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August, 1959

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*Names in italics deceased

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JOURNAL

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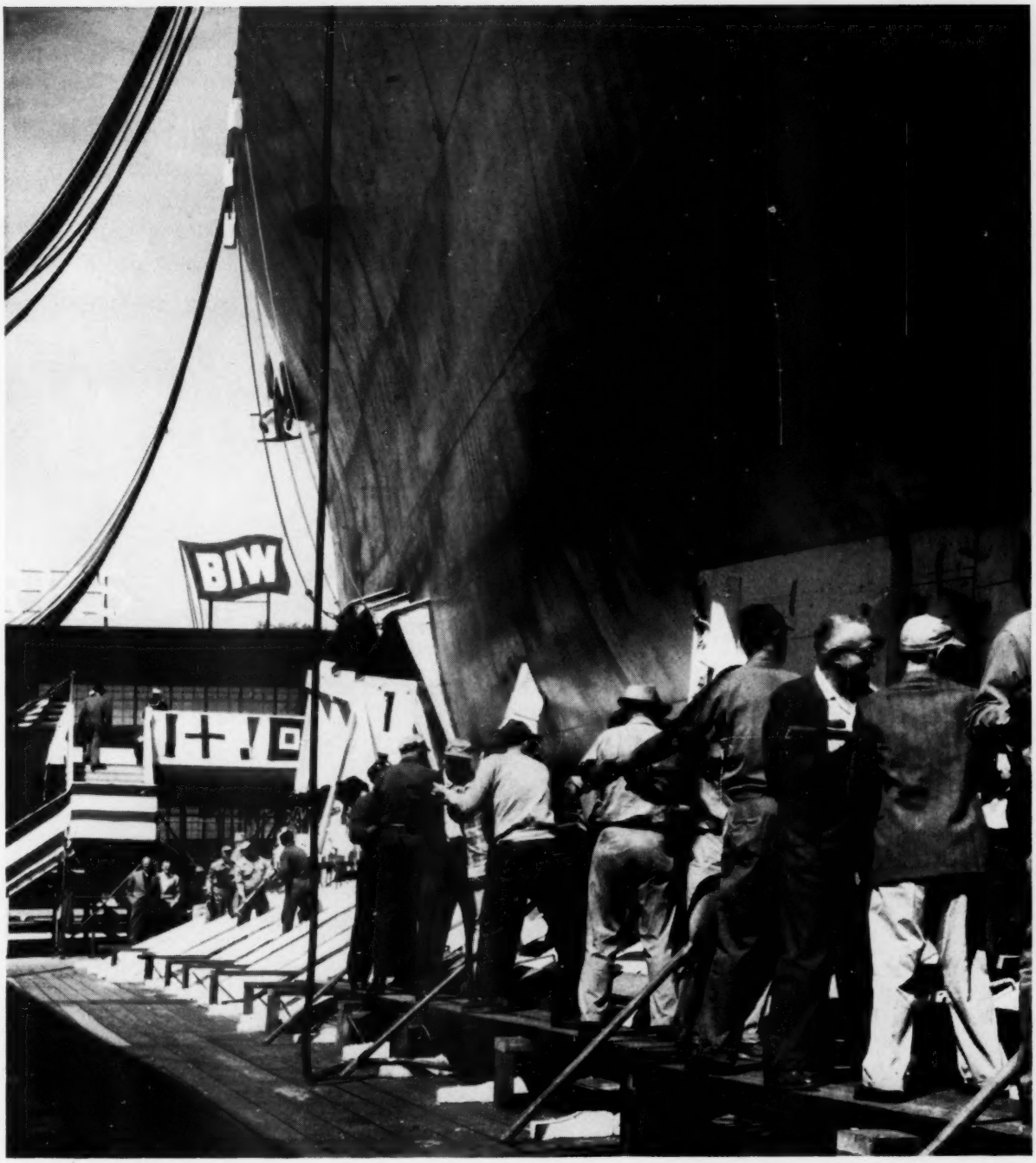


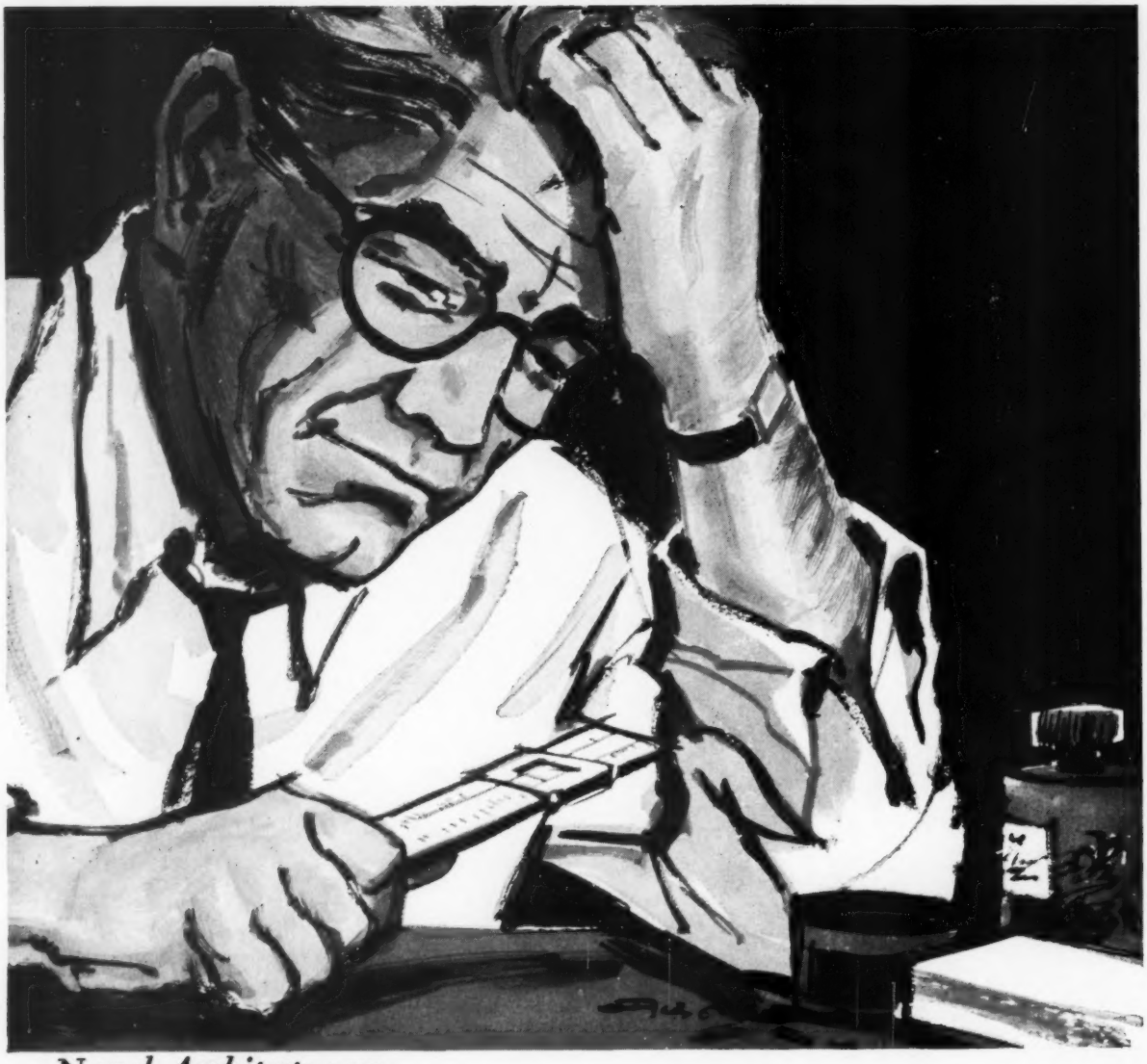
The wedging up of the U.S.S. PREBLE (DLG 15) on her launching day, May 23, 1959.

Bath also built DD 345, the last previous ship of the fleet named in honor of Commodore Edward Preble.

BATH IRON WORKS

Shipbuilders & Engineers

BATH, MAINE



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U.S.S. SAVANNAH 1918
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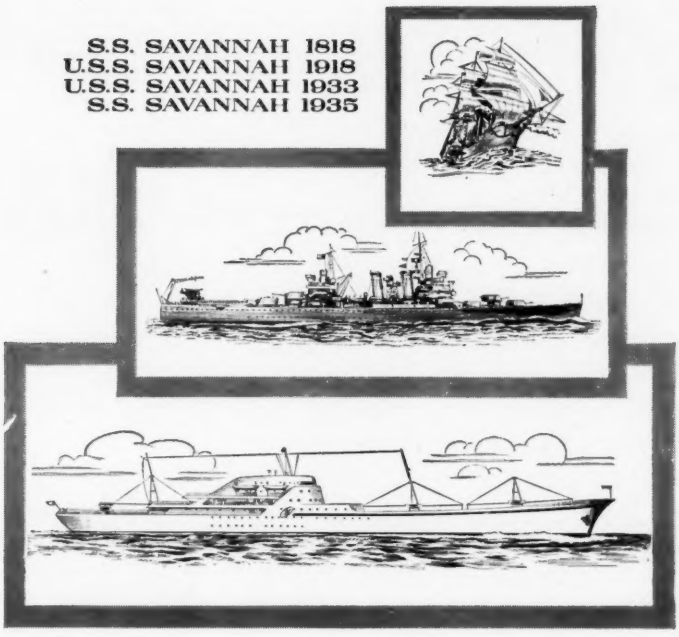


IN 1960, POWER BY B&W WILL DRIVE THE NEW

N.S. SAVANNAH

WORLD'S FIRST NUCLEAR MERCHANT SHIP

Here is marine history in the making. This, the fifth American "Savannah," introduces tomorrow's U.S. Merchant Fleet today. This Atomic-Age pioneer will run approximately 3 years without refueling on a nuclear system designed, built and erected by B&W Engineers.

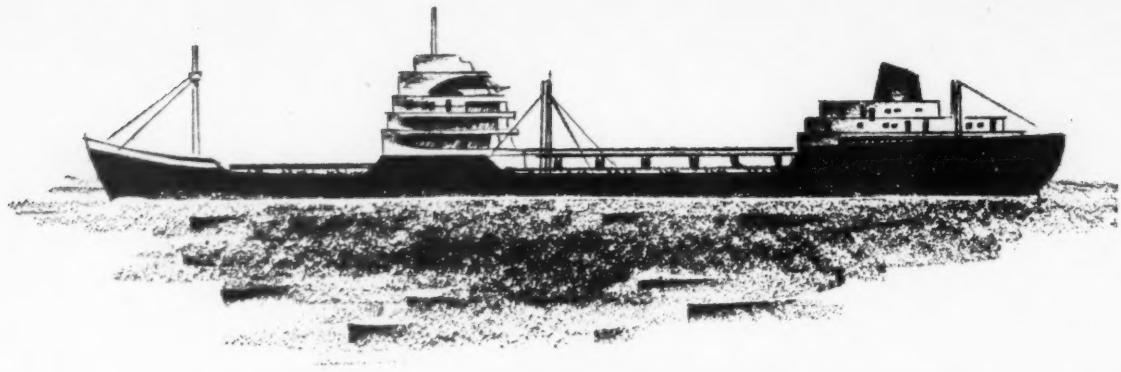
The oldest "Savannah," built in 1818—about 50 years too early to have the advantages of a B&W boiler—was also a pioneer. She was the first *steamer* ever to cross the Atlantic.

After her came the SAVANNAHS 1918 . . . 1933 . . . and 1935. All steam-powered . . . and all steam-powered by B&W.

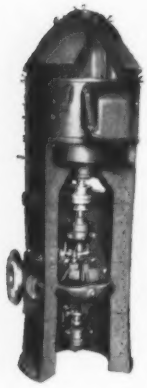
Since 1875, when B&W installed its first marine boiler, The Babcock & Wilcox Company has been the accepted leader in marine power. B&W is proud of its part in this significant forward step in marine engineering and in the peaceful use of the atom. The Babcock & Wilcox Company, Boiler Division, Barberton, Ohio.

M-411

B&W THE BABCOCK & WILCOX COMPANY
BOILER DIVISION



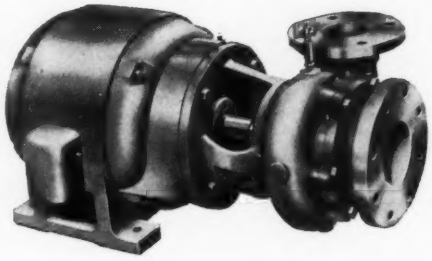
BUFFALO PUMPS-RELIABILITY FOR MARINE SERVICE

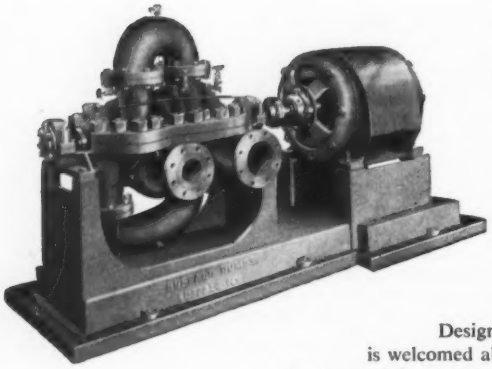


Where reliability, ease of servicing, low maintenance requirements and high efficiencies are important factors governing your selection of marine pumps, specify and install "Buffalo" for complete satisfaction. Buffalo Pumps have proven their ability on thousands of marine installations on tankers, submarines, passenger liners and naval craft. Here are brief details on three widely used "Buffalo" models.

"BUFFALO" VERTICAL DOUBLE SUCTION PUMPS

These "Buffalo" pumps are widely used for clear water handling. Their compact design saves valuable space. Vertically split pump casing affords easy access. Detaching one side of casing permits inspection of impeller and removal of complete rotor assembly. Casing has easily renewable bronze wearing rings. Available in capacities to 14,000 GPM.





"BUFFALO" CLOSE-COUPLED SINGLE SUCTION PUMPS

For "close quarters" installations, particularly where headroom may be a problem, the "Buffalo" Close-Coupled Pump has proven effective. Offered in six models, almost unlimited applications are possible. Pump is rigidly attached to motor with easy access to stuffing box for adjustment. Pump shaft is extended motor shaft, designed for minimum deflection, maximum strength. Wide interchangeability of parts reduces spare parts inventory. Capacities to 1100 GPM. Bulletin 975-F.

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Designed for smooth, vibrationless operation, the "Buffalo" Multistage Pump is welcomed aboard ships where quiet performance is especially desirable. Available in two and four stage models in several sizes. May be used on clear water, hot or cold at pressures up to 1500 ft. head and at capacities from 20 GPM to 900 GPM. Typical "Buffalo" "Q" Factor Quality construction is used throughout as in all Buffalo Pumps. Bulletin 980 for details.

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LARGEST Great Lakes Ship

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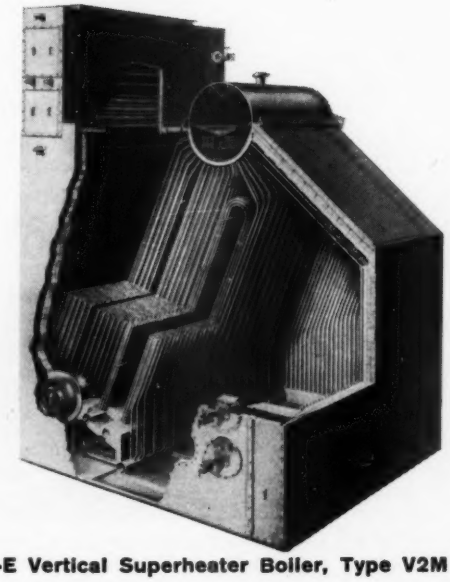

C-E Vertical Superheater Boiler, Type V2M

The Edmund Fitzgerald, largest ship on the Great Lakes, was built by Great Lakes Engineering Works for The Northwestern Mutual Life Insurance Company. She is chartered to Oglebay Norton Company and is operated by its Columbia Transportation Division.

This big bulk carrier has a carrying capacity of a million tons per season. Since a season on the Lakes is limited to about 7½ or 8 months, such results can only be achieved by a schedule which calls for a maximum number of cargoes with minimum turn-around time. Obviously, the maintenance of such a schedule depends upon the service reliability of equipment, since there is no opportunity for major machinery repairs.

The Fitzgerald is equipped for that kind of service with two C-E Vertical Superheater Boilers, Type V2M, fitted with tubular air heaters for heat recovery. Each of these coal-fired boilers is rated at 32,700 pounds of steam per hr., normal . . . and 36,000 pounds per hr., maximum.

C-221

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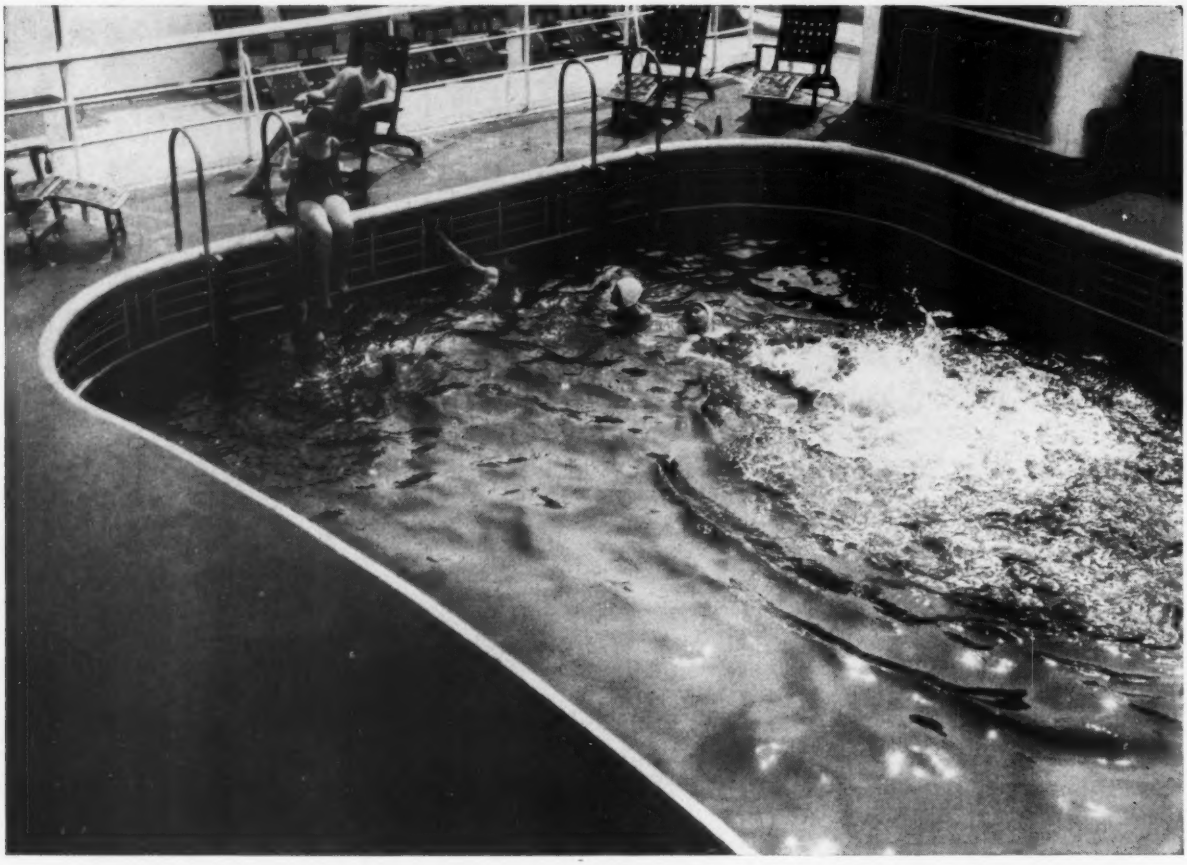


Grace Line's new *Santa Rosa* has the largest outdoor swimming pool on any ship. Clad with Monel, it is more sanitary and easier to maintain than tile, which often cracks with a ship's movement. The pool is 34 feet by 22½ feet. Its constantly changing 38,500 gallons of water are prevented from spilling over the deck by a Monel grilled overflow completely circling the under edge.

Aboard the new Santa Rosa...

In largest outdoor pool afloat— corrosion-resisting Monel does swimmingly well

Seagoin' Monel* makes a big splash on the *Santa Rosa!* For the swimming pool of this 25-million dollar liner—the largest outdoor pool on any ship—is lined with Lukens Monel-clad steel plate. That means there'll be no cracking from the ship's movement in *this* pool, which is so often the case with tile pools.

The *Santa Rosa's* designers realized that Monel nickel-copper alloy provides the perfect combination of sea water corrosion resistance, easy maintenance and handsome appearance, plus the strength of structural steel. And with Monel under the coated beach area *around* the pool, peeling or paint chipping will be no worry, either.

Seagoin' Monel can be the answer to many of your metal problems. In deck fittings . . . in salt water evaporators . . . valve stems . . . valve trim and in many other marine uses, Monel alloy gives long service life where corrosion is a problem.

When you're designing or refitting a ship, depend on Monel to do as much for you as for the designers of the *Santa Rosa's* pool. Wherever metal is subject to corrosive attack, Inco Nickel Alloys offer the protection you want.

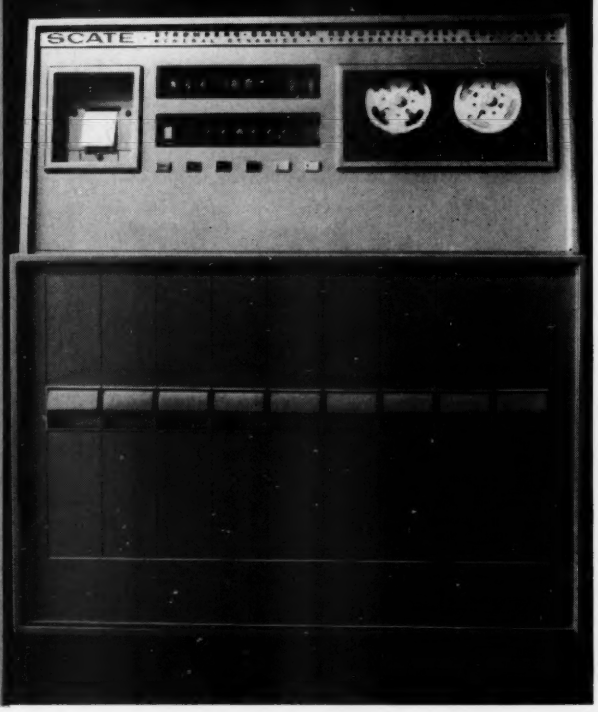
You can also depend on Inco's corrosion engineers for assistance. Just send in your questions and our technical staff will be glad to suggest practical solutions.

*Monel and Seagoin' are registered trademarks of The International Nickel Company, Inc.

Underway at sea, the Grace Line's new *Santa Rosa* heads for the Caribbean. She was built by the Newport News Shipbuilding and Dry Dock Company especially for warm weather cruising—air conditioned throughout and with generous space for outdoor recreation.

The INTERNATIONAL NICKEL COMPANY, Inc.
67 Wall Street New York 5, N.Y.

A TALENT FOR WEAPONS TEST EQUIPMENT



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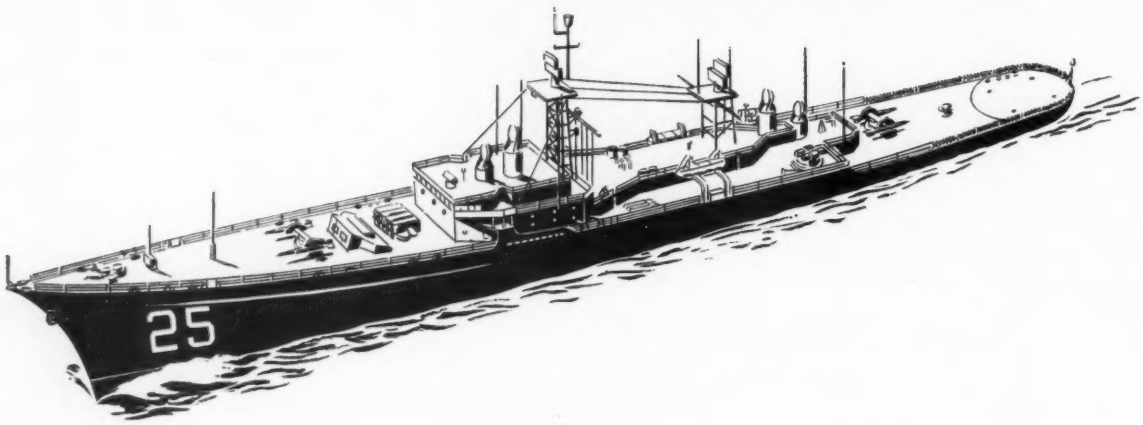

A vital link in the U. S. Navy's atomic fleet was forged on May 15, 1959, when our Quincy, Mass., shipyard laid the keel for the first nuclear-powered guided-missile frigate, DLG(N)-25. The sketch above is an artist's conception of the ship, which will bear the name of Commodore William Bainbridge of Old Ironsides fame. Scheduled for completion early in 1962, the Bainbridge will have an over-all length of 540 feet, breadth of 56 feet, displacement of approximately 7,600 tons, and virtually unlimited cruising radius.

With the nuclear submarine already in service, and construction well underway on the first nuclear aircraft carrier and first nuclear cruiser, the DLG(N) is another important component in our Navy's combat fleet of tomorrow. Fast and powerful, with unparalleled anti-aircraft and anti-submarine weapons, she will assume the dual role of the conventionally powered light cruiser and destroyer.

Already under construction at our Quincy Yard is the 14,000-ton, guided-missile nuclear cruiser, USS Long Beach. Scheduled for completion in 1960, she will be our Navy's first atomic surface warship.

Bethlehem's pioneering work in the field of marine nuclear propulsion was a major consideration in selecting the builder of these vital ships. It's another example of how Bethlehem serves our Navy and our nation.

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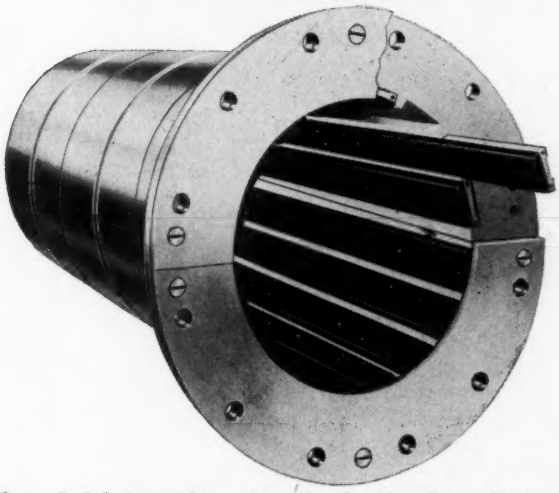
Stern Tubes and Struts



Soft rubber bearing surface—efficiently lubricated by water—this bearing far outlasts all hard surface types, protects propeller shafts, reduces vibration. More than pays for itself in extra wear alone. Saves you time, trouble, and upkeep expense.

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Incombustible Joiner Materials • Acoustical Materials
Asbestos Ebony for Switch and Panel Boards • Structural Insulations
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Box 290, New York 16, N. Y.

H. NEWTON WHITTELSEY Inc.

NAVAL ARCHITECTS **MARINE ENGINEERS**

17 BATTERY PLACE, NEW YORK 4, N. Y.

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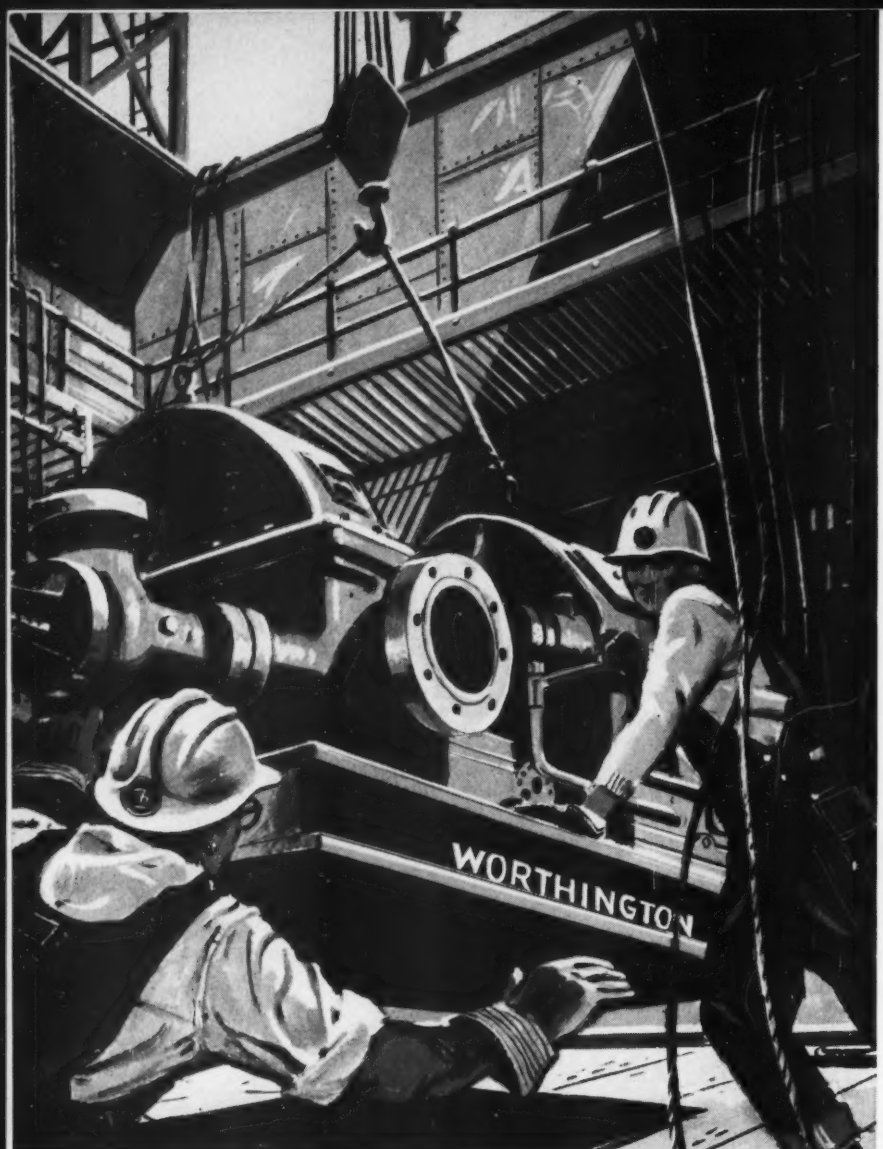
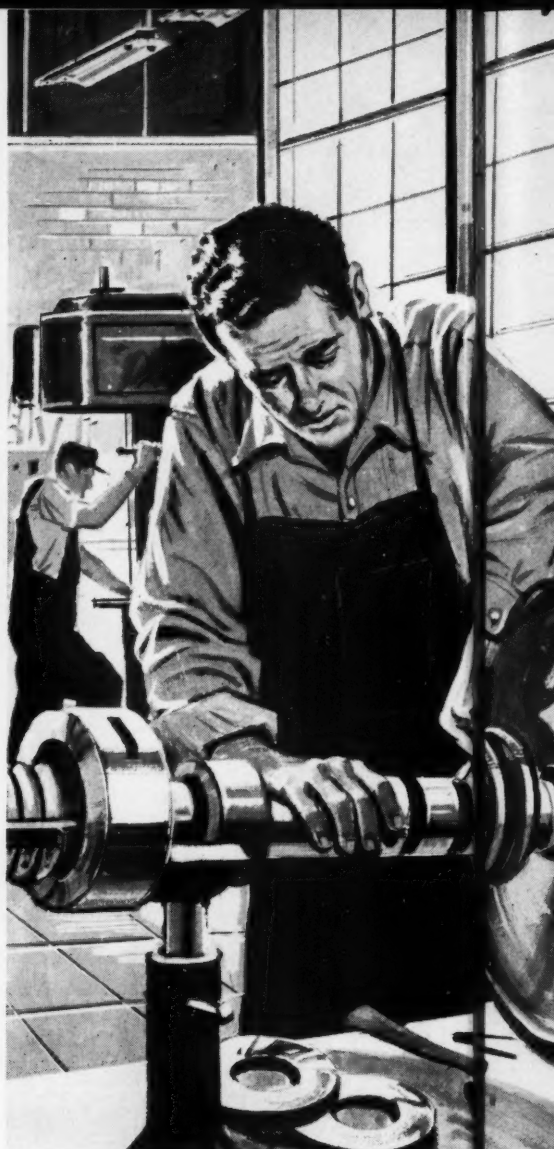
M. ROSENBLATT & SON, Inc.

NEW YORK CITY
350 BROADWAY
BEekman 3-7430

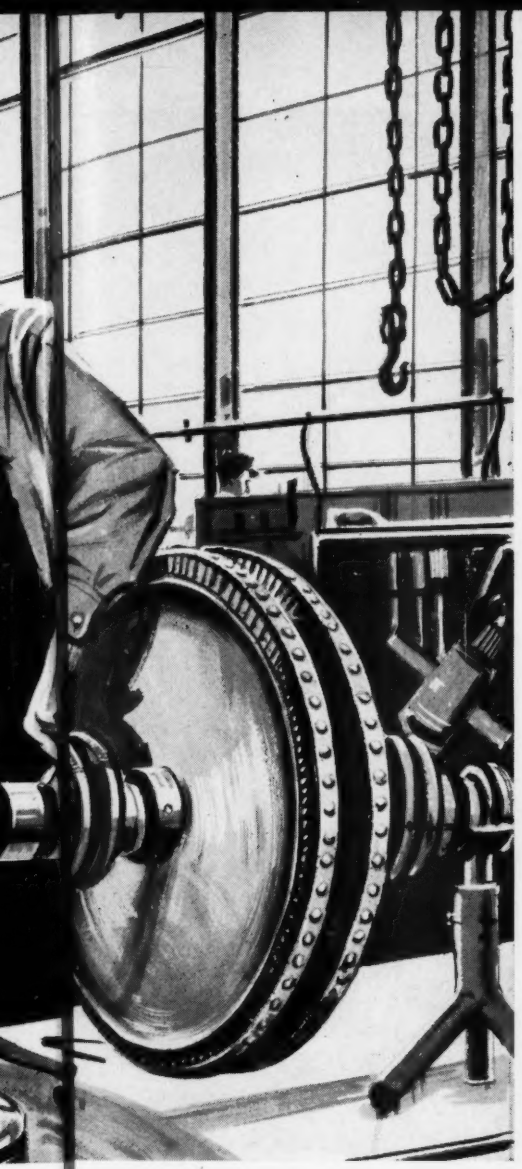
SAN FRANCISCO
216 MARKET ST.
EXbrook 7-3596

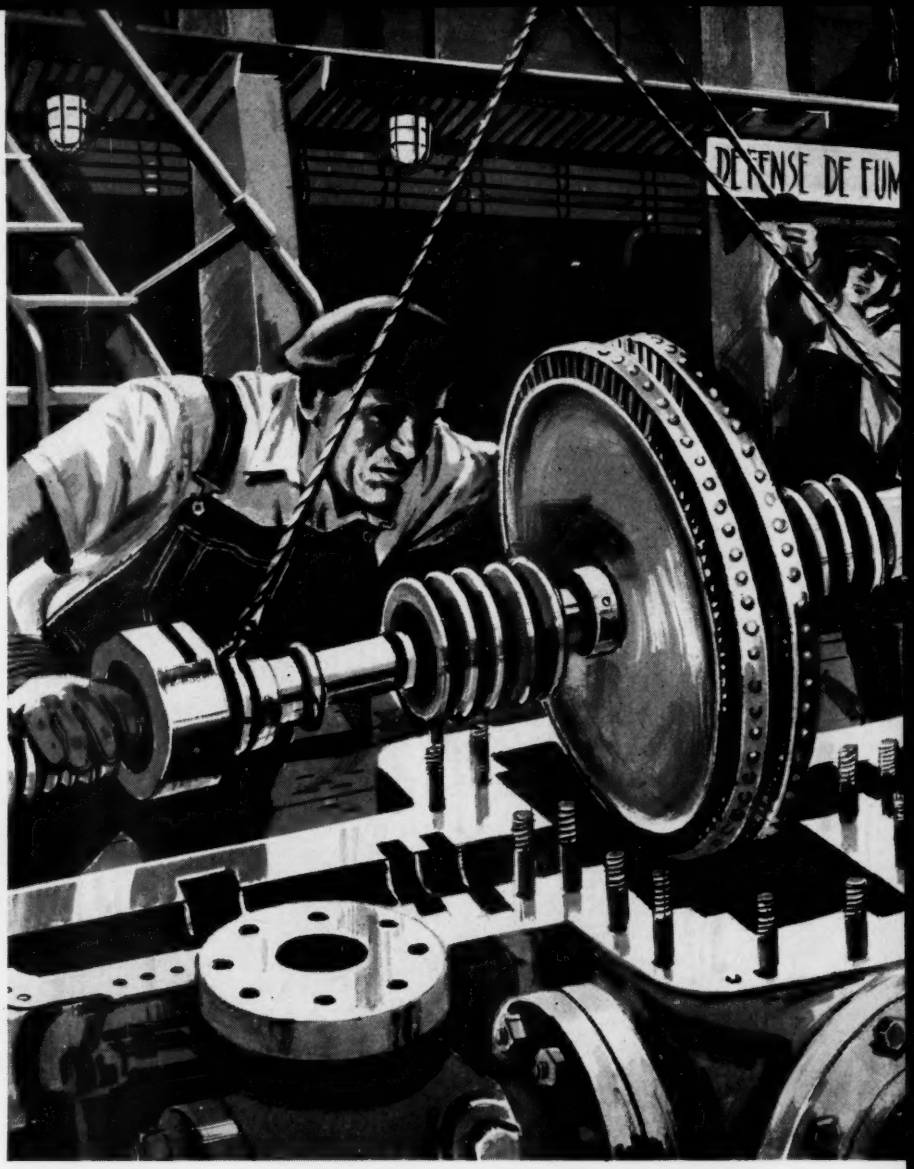




INSTALLED IN JAPAN... REPAIRED

WORTHINGTON MARINE SERVICE COVERS THE GLOBE. No less than 121 foreign distributors and 12 separate foreign manufacturing plants assure you of Worthington Marine Service nearly anywhere a ship can dock.





IN U.S.A....SERVICED IN FRANCE

Turbo-Tanker VENTURE Saves Weeks of Time Because Worthington Marine Service Spans the World

This is the story of Tanker Ventures S.A.'s 21,000 ton tanker, T/T VENTURE.

The T/T VENTURE was built in the Uraga shipyards in Japan. The main cargo oil pumps and turbines were supplied by Niigata Worthington Co., a subsidiary of the parent corporation. The equipment was installed under the careful supervision of Niigata's marine specialists.

On March 6, 1959, during the annual survey tests in Italy one of the turbine rotors was seriously damaged. The Owners asked Worthington's Marine Division to manufacture a replacement rotor and parts as soon as possible. Worthington's Wellsville, N. Y., plant completed the job in record time but . . .

. . . T/T VENTURE'S next port of call was Lavera, France. So Worthington shipped the replacements by air to France to await the ship. The vessel arrived April 1 and the job was supervised by a service engineer from Societe Worthington, our French associated company which has complete facilities for both manufacture and service of Worthington products.

Unusual? Yes and no. Yes, it's unusual that one ship would require the services of three widely separated Worthington facilities. No, it's not unusual for a vessel in trouble to find Worthington Marine Service at its next port of call. Around the world there are 121 Worthington foreign distributors and 12 separate manufacturing plants. Many of these offer you fast service combined with an extensive line of marine auxiliary equipment.

For more information about Worthington's complete line of pumps, compressors, steam turbines, diesel engines, condensers, deaerators, ejectors, and refrigeration and air conditioning equipment, write to Worthington Corp., Section 106-3, Harrison, N. J.

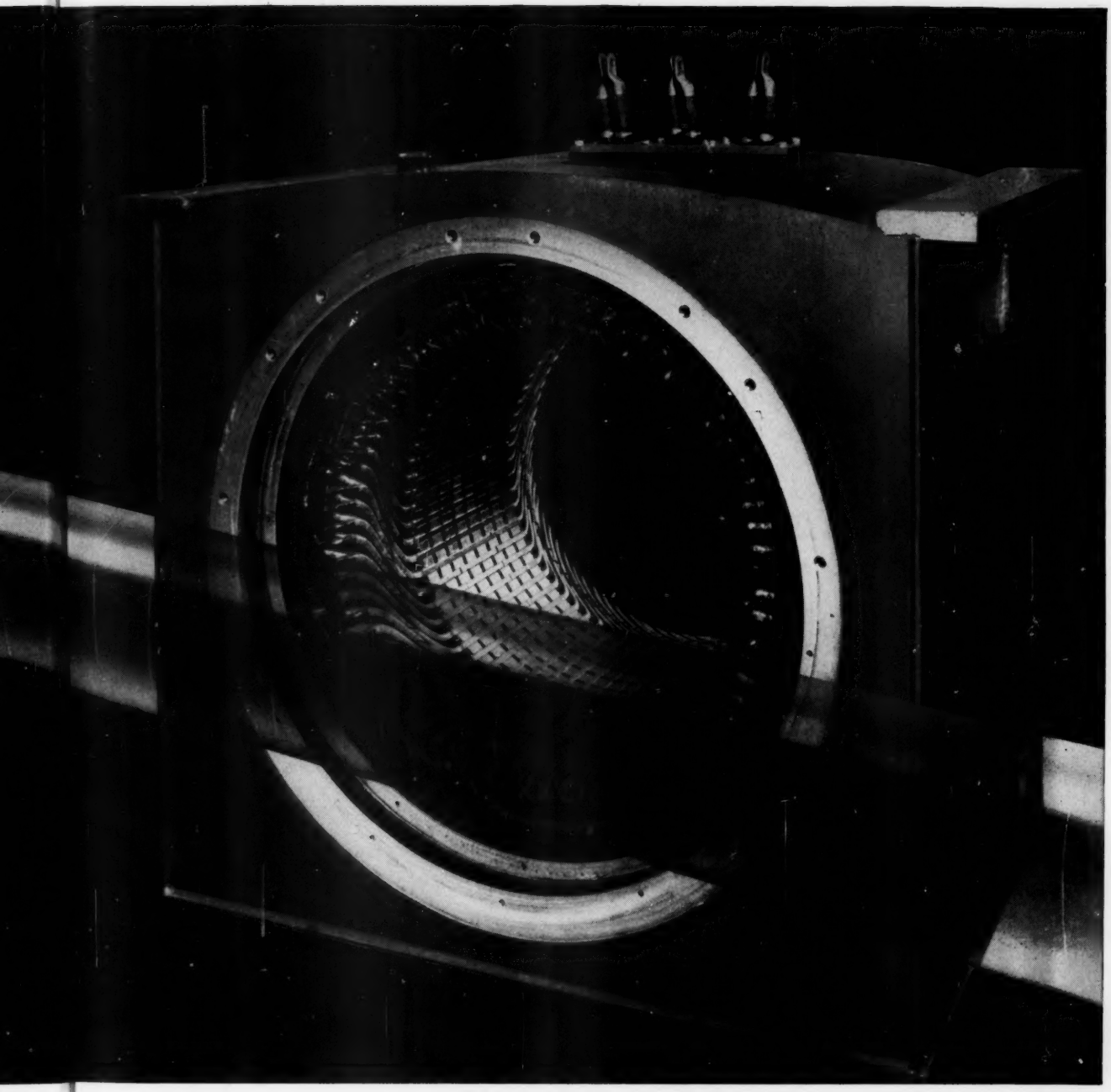
WORTHINGTON

Westinghouse Thermalastic insulation

Thermalastic® insulation on motor and generator coils lasts 10 times as long as conventional insulation, even under the rigorous conditions and salt-laden air of marine service. Still, the cost is no higher than ordinary insulations. This is an example of Research by Westinghouse which creates better, longer-lasting marine auxiliary and propulsion equipment.

Conclusively proved in years of operations, Thermalastic insulating systems have a tensile strength 30 times normal and will withstand over-voltages without failure far longer than conventional insulations. With such prolonged coil life, simple bearing maintenance results in maximum reliability and trouble-free service from motors and generators.

You can obtain this exclusive, patented Thermalastic protection for your equipment *now* at no



makes generators last 10 times longer

additional cost over conventional insulation, whether you are repairing old equipment or installing new. Take advantage of this and many other unusual Westinghouse developments in selecting the equipment for your next ship construction. Contact your local Westinghouse sales engineer or write, Westinghouse Electric Corporation, 3 Gateway Center, P. O. Box 868, Pittsburgh 30, Pa.

A marine generator stator insulated with Thermalastic®. This exclusive, patented resin penetrates and bonds with mica flakes to become a tough, flexible, void-free casing that expands and contracts with the coils, yet never splits nor cracks.

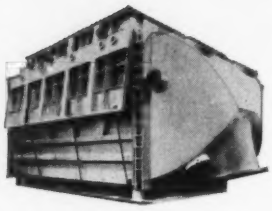
J-92026

YOU CAN BE SURE... IF IT'S

Westinghouse

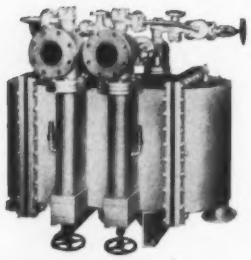
WATCH "WESTINGHOUSE LUCILLE BALL-DESI ARNAZ SHOWS" CBS TV MONDAYS

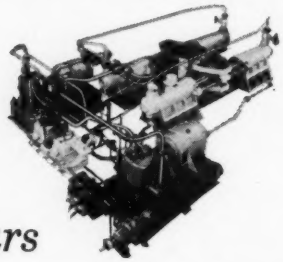
For



Marine Condensers,

C.H. Wheeler Condensers, main and auxiliary, occupy little room, weigh comparatively little, have Center Lane Tube Layout to speed longitudinal steam travel and permit quick penetration of steam to bottom row of tubes.

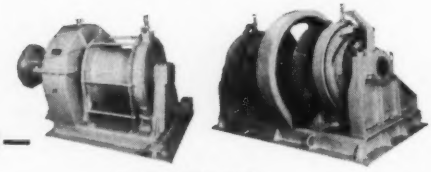




Tubejet® Ejectors, Steering Gears

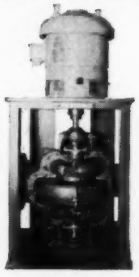
C.H. Wheeler Tubejet ® Ejectors answer problems raised by today's high boiler pressures and temperatures. They remove large quantities of vapors at high vacuums. Light, compact, dependable, too!

Electro-Hydraulic Steering gears are available in a complete range of sizes for every type vessel, from tug boats to supercarriers. C.H. Wheeler also makes automatic, self-centering, springless telemotors and rotary telemotors.



and Telemotors— Deck Machinery and

C.H. Wheeler Deck Machinery includes Electric and Hydraulic Winches, Electric Hydraulic Windlasses, Electric Warping Capstans, Boat and Aircraft Cranes, Automatic Tensioning Hoists and Elevators.



High-Capacity Corrosion-Proof Fire Pumps; for

Corrosion-Proof Fire Pumps designed and manufactured by C.H. Wheeler provide maximum gpm at medium and high heads; offer dependable, low-maintenance performance and take little space in the hold.

nearly everything

but the hull, see:

Marine Division

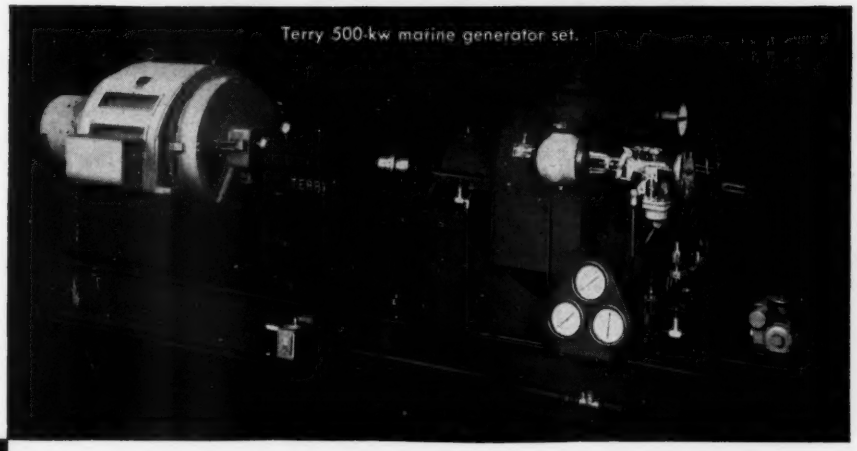
C. H. WHEELER MFG. CO.

19TH & LEHIGH AVENUE
Philadelphia 32, Pennsylvania

Whenever you see the name C. H. Wheeler on a product, you know it's a quality product

Marine Condensers, Ejectors, Pumps and Auxiliary Machinery • Steam Condensers • Steam Jet Vacuum Equipment • Centrifugal, Axial and Mixed Flow Pumps • Nuclear System Components

Terry steam turbines


Terry 500-kw marine generator set.

Terry solid-wheel turbine with upper half of casing removed.

Dependable, compact, efficient . . . Terry marine turbines are specially designed for driving generators, boiler-feed pumps, fuel-oil pumps, compressors, etc., aboard ship. They are the result of over fifty years of experience in designing equipment for commercial and naval vessels.

Turbines ranging from 5 to 3000 hp are built in the Terry solid-wheel design as well as in axial-flow, single-stage and multi-stage types.

Complete details of turbines for any application will be gladly furnished.

THE TERRY STEAM TURBINE CO.
TERRY SQUARE, HARTFORD 1, CONN.

TT-1211

KINGSBURY THRUST and JOURNAL BEARINGS

THE NAVY'S CHOICE FOR 40 YEARS

Kingsbury Machine Works, Inc. KINGSBURY **Frankford, Philadelphia 24, Pa.**

DE LAVAL
MARINE PROPULSION UNITS

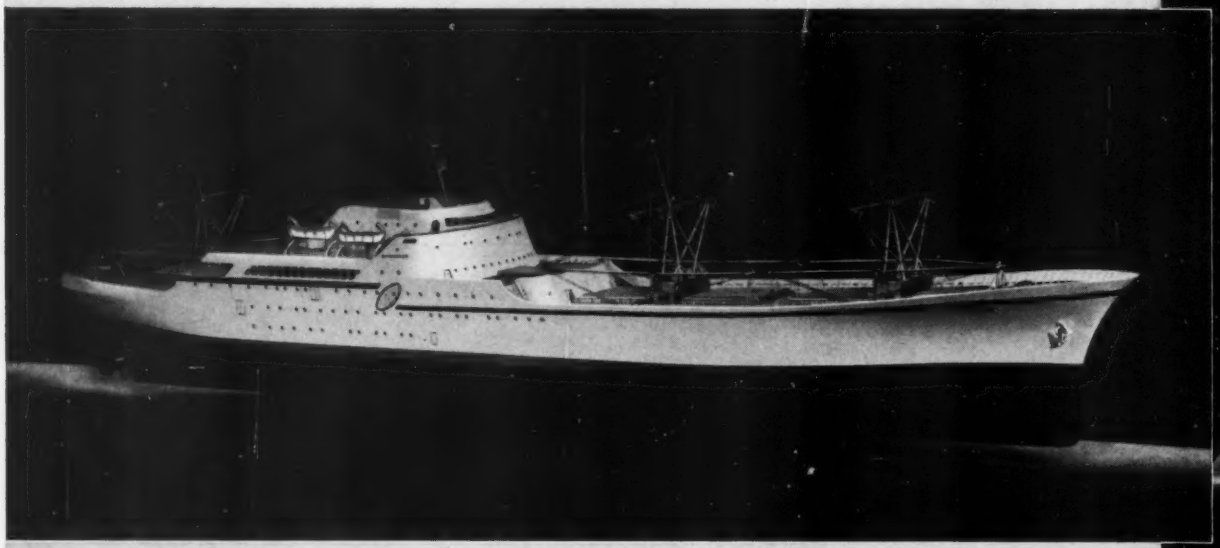
DE LAVAL

Shown at the right are the powerful main propulsion turbines and double helical, double reduction gears that will power the world's first nuclear merchant vessel, the N.S. SAVANNAH.

This propulsion unit will develop a maximum continuous horsepower of 22,000 when operated with dry and saturated steam ranging in pressures from 430 PSIA to over 700 PSIA with a condenser vacuum of 28.5" Hg.

De Laval has played an important part in the design and construction of the machinery for this nuclear ship as well as for a new nuclear-powered submarine.

These examples of leadership in the marine industry illustrate the dependability and precision manufacture that have made the name De Laval synonymous with quality for over half a century.



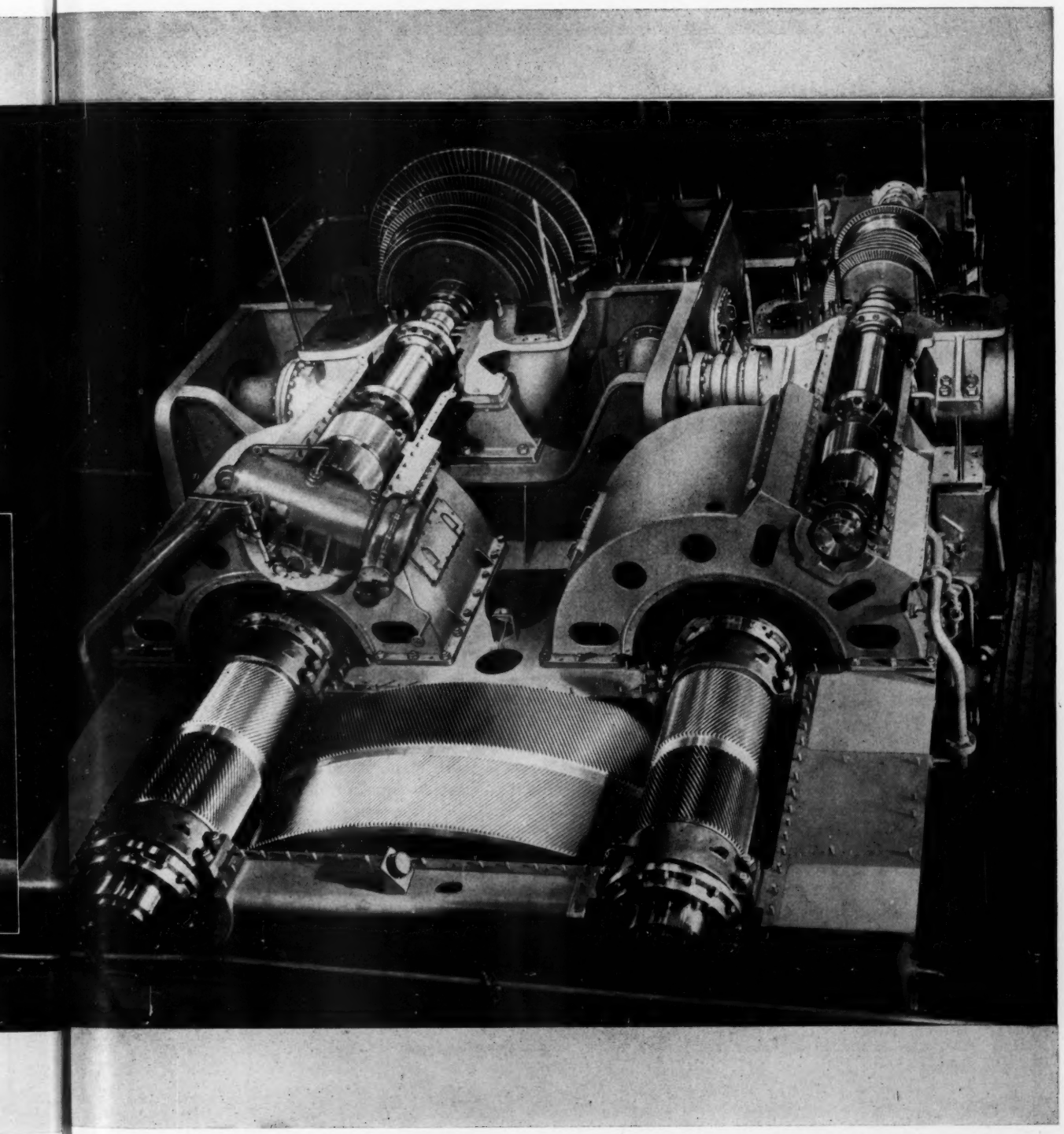
Model of N.S. Savannah • George G. Sharp, Inc., naval architects, designers of the vessel
• The Babcock & Wilcox Company, prime contractor for the nuclear propulsion system
• New York Shipbuilding Corp., Camden, N. J., builders of the vessel

DE LAVAL *Steam Turbine Company*

NOTTINGHAM WAY, TRENTON 2, N. J.

DL-486

propulsion units to drive N.S. Savannah



Dry Dock No. 2

* "We shall build good ships here, at a profit if we can, at a loss if we must—but always good ships."

Collis P. Huntington, founder (1886)

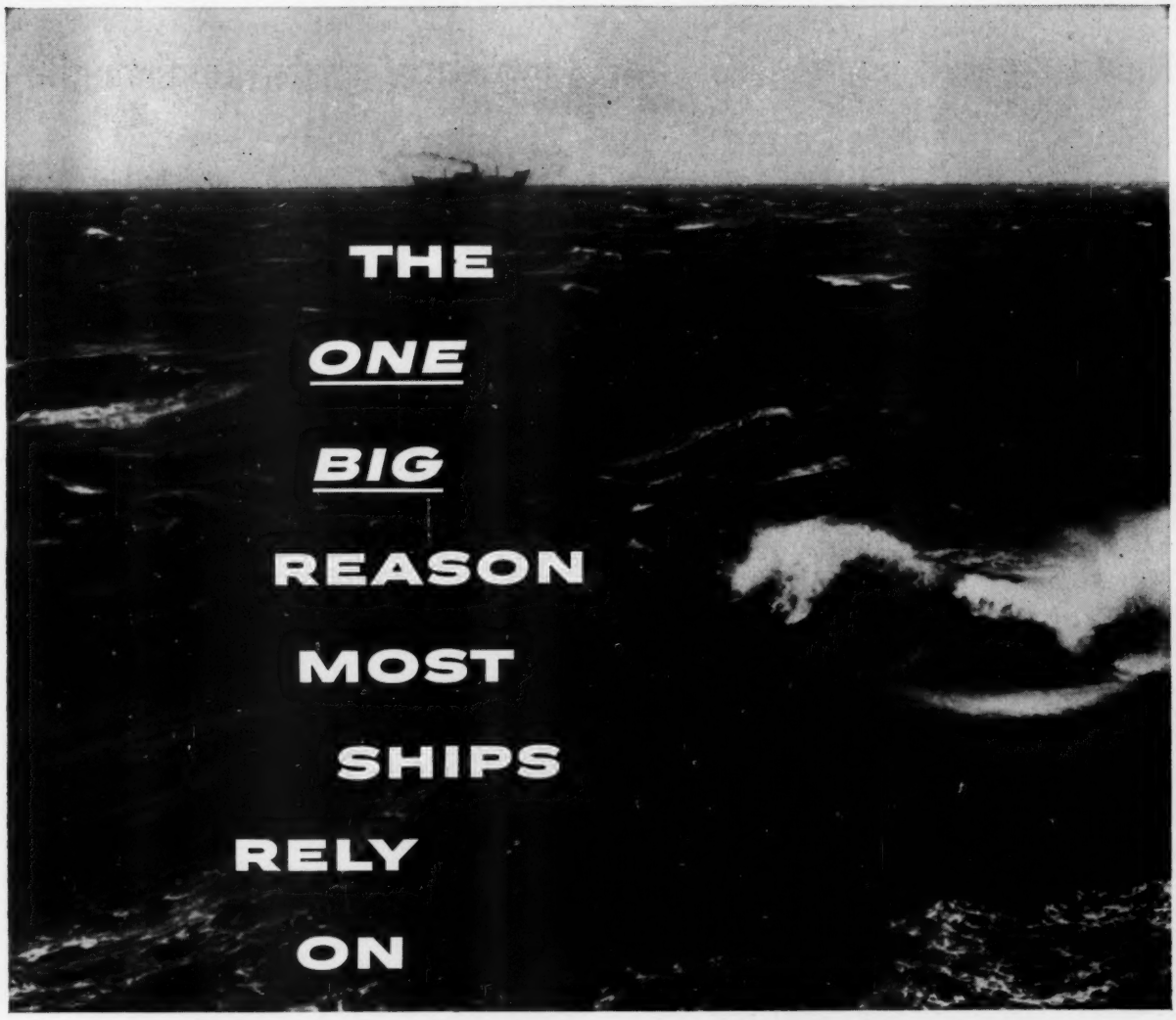
Newly enlarged and modernized for more good* ship repair

Newport News' Dry Dock 2 was recently enlarged and modernized to provide additional facilities to repair today's larger ships—faster and more economically. This modern graving dock, built for drafts up to 30 feet over its sill, will accommodate ships up to 850 feet in length with a 116-foot beam.

With a total of five graving docks, including two huge docks accommodating ships 960 and 1100 feet long, respectively, Newport News has the facilities to repair ships of any size. As the world's most fully integrated shipyard, it is equipped to do good ship repairs in the shortest possible time.

Engineers . . . Desirable positions available at Newport News for Designers and Engineers in many categories. Address inquiries to Employment Manager.

Newport News
Shipbuilding and Dry Dock Company
Newport News, Virginia



LESLIE FOR CONTROLS

Out here, if a control valve or regulator fails there's no place to go for repair facilities or replacement parts. Delay can mean late arrival, cargo spoilage and loss of profit. Shipowners, operators and builders are aware of this hazard. That's why 95% of America's merchant and naval vessels are Leslie-equipped.

This overwhelming preference for Leslie is based on sound reasons. Leslie reliability means trouble-free service, maximum resistance to corrosion and wear, and lower overall operating cost. Leslie quality is based on nearly 60 years of experience in designing and producing equipment for the marine industry.

Leslie products include *reducing valves* for steam, air and water services; *temperature regulators* for steam and water systems; *pump pressure regulators* for steam driven pumps and turbines; *pilot mechanisms and diaphragm control valves* for liquid level and pressure and temperature control; and Leslie-Tyfon steam and *air whistles*. Write for complete engineering and application data.

TRADE LESLIE MARK **REGULATORS and CONTROLLERS**

Leslie Co., 413-B Grant Ave., Lyndhurst, New Jersey

ENGINEERED FOR MARINE SERVICE

Diaphragm control valves

Control pilots for pressure, temperature and level

Pressure reducing valves

Temperature regulators

Pump pressure regulators, Differential pressure regulators

Strainers

Steam and air whistles, automatic whistle controls

New tube mill equipment gives designer of heat-transfer units freer hand in meeting new trends

With the installation of new production and testing equipment, The American Brass Company now offers the most complete service available to users of condenser and heat exchanger tubes.

Long Lengths. To gain advantages in construction, processing, or installation, designers can lengthen equipment considerably. Tubes can now be drawn up to 100 feet. Most of the longer tubes are required as U-bends, but in some instances may be shipped as straight lengths.

U-bends. Tubes from ⅜″ O.D. to 1½″ O.D. with wall thicknesses from .049″ (18BWG) to .134″ (10BWG) can be bent on a radius of from 1¼ times the tube O.D. to 30″.

Dual Gage. Where high temperatures and pressures are involved, it may be desirable to thicken the tube wall in the area of short-radius bends on U-bend tubes. Walls are thickened one Stubs' Gage No. to compensate for thinning of metal in the bending.

Thickened Tube Ends. To compensate for thinning by rolling or by impingement corrosion caused by high velocities, tubes may be supplied with the wall thickened at one end one or more Stubs' Gage Nos. The extra thickness may be on the outside or inside of the tube as required.

Relieving Stresses. All U-bend tubes, other than copper, are annealed at the bend area after bending, to eliminate the hazard of stress-corrosion cracking which might occur in service due to stresses that may exist as a result of the bending.

Testing. U-bends are tested hydrostatically at ASTM Specification pressures—or at ASME Code pressures up to 6000 psi on request, if the tube size will stand it. Electronic inspection with eddy-current equipment is available also, when required.

Shipping. U-bend tubes are shipped packed for ease in handling and storage.

Technical Assistance. For more detailed information on extra-long tubes, U-bend, Dual-gage, or Duplex tubes to meet special problems, address: The American Brass Company, Buffalo Division, Buffalo 5, New York. In Canada: Anaconda American Brass Limited, New Toronto, Toronto 14, Ontario. 5957B

ANACONDA®

Tubes & Plates for Condensers & Heat Exchangers made by The American Brass Company

GIBBS & COX, INC.

NAVAL ARCHITECTS

AND

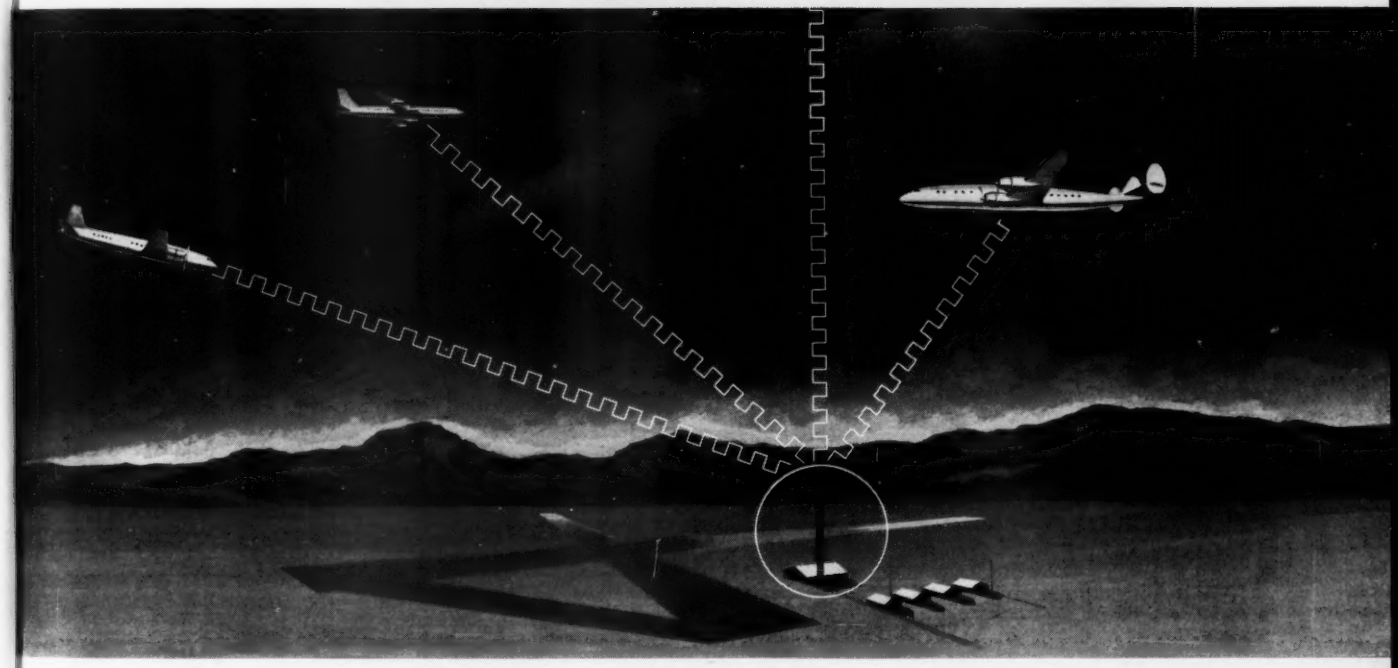
MARINE ENGINEERS

NEW YORK

new wings for words

AGACS

pronounced "AJAX"



AGACS, Experimental Automatic Ground/Air/Ground Communication System is a new concept in Air Traffic Control Communications to meet the accelerated pace of increased air traffic. Primary objectives are efficient usage of frequency spectrum, added safety through increased reliability and reduced burden to pilot and controller, and adaptability to all classes of aircraft. AGACS provides compatibility with existing ground and airborne communication equipment, selective addressing of information, and a minimum number of frequency changes during flight. The system utilizes two-way time division data transfer over existing ground and air communication links to provide an automatic, mutual exchange of information. The airborne facilities display to the pilot the last significant Air/Ground and Ground/Air message quantities, while the controller may recall from central memory-storage equipment the last Air/Ground and Ground/Air message quantities for display. The AGACS program is still in the developmental stage. In August, 1959, RCA provided initial models of both airborne and ground equipments for the Bureau of Research and Development of the Federal Aviation Agency for extensive experimentation and flight tests.

RCA

Tmk(s) ®

RADIO CORPORATION of AMERICA

DEFENSE ELECTRONIC PRODUCTS

CAMDEN, N. J.

Official United States Navy Photograph

USS *Macon* is shown in the St. Lawrence Waterway, moving into the Great Lakes as a part of the Navy fleet taking part in the ceremonies marking the opening of this great new trade route. Accompanied by a group of destroyers, the naval force carrying midshipmen of the U. S. Naval Academy gave the Great Lakes region its first glimpse of an operating unit of the modern Navy.

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Journal of the AMERICAN SOCIETY of NAVAL ENGINEERS, Inc.

VOLUME 71 AUGUST, 1959 NUMBER 3

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NAVAL ENGINEERING

Definition: NAVAL ENGINEERING is the art and science applied in the design, construction, operation and maintenance of naval ships and their installed equipment.

SECRETARY'S NOTES

Naval Engineers

We have been seeking, for some time, a rationale for explaining the American Society of Naval Engineers and why men belong to it. There is something very nebulous about the whyness of Societies. Many of the reasons that apply to other Societies cannot be applied to ASNE.

Our Society offers no material advantages to a member. We do not help him to find a job. We do not push his promotion, we don't even give him a preferred outlet for his writing because no preference is shown to an author because of his membership.

Our Journal is unique and we believe, good. We know of no other country, including Russia and England, the new and the old claimants to share leadership in Naval Engineering with the United States, which publishes a comparable Journal.

Our annual banquet is one of the best large social gatherings of a professional group held anyplace in the world. Many consider it *the* best.

Although there is no doubt that the Journal and the Banquet are the patent reasons for many members to spend ten dollars a year, these are not the basic reasons for most of them. Also, both can be attained by nonmembers. We believe that we have

found a clue in this issue of the JOURNAL which is not too different in a general way from any other issue.

The Naval Engineering profession, we are sure, has never sat on its hands nor rested on its oars. There has always been a restlessness against being satisfied. The end product of the profession is a naval ship or anything which contributes to the construction or maintenance or operation of a naval ship. Those responsible for the end product are never satisfied and even when they have no money for converting ideas into hardware, they dream of the better ships when the fiscal skies brighten. In each of the contributing professions such as naval architecture; mechanical, electrical, electronics, chemical engineering (to name but a few); nucleonics, metallurgy and other materials fields, there is also an urge for betterment, for improvement, for producing something to do something which has never been done or to do something better. These two urges when joined have tremendous power and seldom does a day pass without some worthy accomplishment. This we know. This we recognize but all of these accomplishments are not spectacular. We believe that this issue of the JOURNAL comments on or refers to a greater number of outstanding and spectacular accomplishments than one can expect to occur in one three months period. With no attempt to order them as to importance, these things have happened:

1. The world's first nuclear propelled surface combatant ship USS *Long Beach* was launched by The Bethlehem Steel Company at Quincy Massachusetts.
2. The world's FIRST nuclear propelled commercial carrier type ship, NS *Savannah* was launched by New York Shipbuilding Corporation at Camden, New Jersey.
   Note: First in nuclear powered surface ships goes to the Russians for their Icebreaker, *Lenin*. Although this is a practical ship for a very practical purpose it is neither a naval combatant nor a commercial carrier type.
3. The FIRST POLARIS submarine *George Washington* was launched by the Electric Boat Division of General Dynamics Corporation at Groton, Connecticut.
4. The LARGEST combatant ship ever to be side-launched in the U.S. entered the water at Bay City, Michigan at the plant of the Defoe Shipbuilding Company.
5. This ship U.S.S. *Wilson* (DDG7) is the LARGEST combatant ship ever built in the Great Lakes and this was possible because
6. The St. Lawrence Seaway was opened and dedicated providing the FIRST allwater route from the seven seas to the Great Lakes.
7. The U.S.S. *Macon* (CA132) was the FIRST naval cruiser to transit from the Atlantic Ocean to Chicago, Illinois.

When these events are all taken in one package the effect is staggering. We wonder if the knowledge that such events are always in progress in naval engineering and the feeling that they have been, or are, or will be contributors to things like this, doesn't create a spirit of wanting to publicly acknowledge their part, and causes men to join and to belong to the American Society of Naval Engineers. Although the evidence of the profession is very material. is it the spirit or soul of the naval engineer overlying that of his specific profession which lead a man into and keeps him in the Society? To adopt a current popularism, is it a spirit of togetherness in magnificent joint achievement? A small percentage of the many thousands of engineers of all kinds who because of their contribution to these end products become *"Naval"* engineers by this application, make up the membership of ASNE. Does our explanation appeal to any of them?

Change to By-Laws

At its meeting on 9 April 1959, the Council of the Society adopted the following proposed amendment to the By-Laws and instructed the Secretary-Treasurer to include the proposed change in the ballot for officers for 1960-61 which will be mailed this coming fall to all Naval, Honorary and Civil members:

> Article 8. Delete "and Secretary-Treasurer" in the first line. Insert in the second line between "Council" and "shall be elected" the words "except the Secretary-Treasurer."
>
> Article 10. Delete the first sentence and substitute therefore: "The Secretary-Treasurer shall be appointed by the Council from among the Naval Members under such terms as it shall decide upon. The Secretary-Treasurer shall act as Secretary and Recorder of the Council and shall conduct the correspondence of the Society and its financial transactions."

The effect of these changes is that the Secretary-Treasurer will be appointed by the Council for any term which is decided upon, instead of being elected to serve for one year. He will still be a Naval Member as defined in Article 15 of the By-Laws and will continue to be a member of the Council. Of course, this could be affected by action which the Congress may take as a result of the hearings now in progress in regard to the employment of retired officers. Because of the possible enactment of legislation it is considered quite important that the Council have the authority which this change will give it.

If this amendment is approved, the Council will be permitted to take any action desired at any time to appoint a Secretary-Treasurer, without the possible impediment of forcing this employee to seek and obtain annual re-election. The Council believes that it can perform its function of directing and managing the affairs of the Society in a far more satisfactory manner if it, the Council, has a more direct responsibility for selecting its business and editorial manager —the Secretary-Treasurer.

If this amendment is approved by the membership in the 1960-61 ballot, it will become effective on 1 January 1961, or before that date if the elected Secretary-Treasurer becomes ineligible for any cause during calendar year 1960.

We are including this notice in these Secretary's Notes to give the membership plenty of time to fully consider this very important matter in advance of receiving the ballot.

Council Membership

Captain E. H. Batcheller, USN Captain J. A. Brown, USN

OUTGOING

Changes, particularly in the Regular Naval members of the Council, between elections are not uncommon. Whenever the requirements of the Navy demand the service of these officers in some place other than Washington, D. C. or its vicinity, the by-laws of the Society necessitate their replacement.

The Navy's regular June shift removed both of the officers who were elected to Council membership last year from the Washington scene.

Captain E. H. Batcheller, USN who had been serving as Comptroller of the Bureau of Ships was transferred in June to become Supervisor of Shipbuilding and Naval Inspecter of Ordnance at Quincy, Mass. The Council has appointed Commander John A. Coil, USN who is on duty in Code 335 of the Bureau of Ships to serve as a regular Naval member of the Council for the remainder of Captain Batcheller's unexpired term until 30 December 1960.

Captain J. A. Brown, USN served for a few months in 1958 on the Council on an appointment to fill a vacancy. He was then elected for a term of two years. After serving for one-fourth of this term he was transferred from duty in the Bureau of Ships to the New York Naval Shipyard. His unexpired term will be completed by Captain Thomas W. Rogers, USN. Captain Rogers is on duty in the office of the Chief of Naval Operations.

Commander J. A. Coil, USN Captain T. W. Rogers, USN

INCOMING

The Society's 1959 Budget

At the half way point, the budget which was approved by the Council for our 1959 operations appears to be holding its own. No radical changes should be necessary to assure that we reach the end of the year with a modest gain in net worth.

The one uncertain element at this time is the collection from membership dues. A larger number of these are outstanding than we like to see at this time of the year, particularly since the change in the by-laws last year no longer permits these to be carried for two years. On the bright side the response to the second notice has been reasonably good.

The budget will be considered by the Council at a meeting to be held in August, too late to report in this issue.

The Brand Award

The Brand award was established in 1954 by Mrs. Brand in memory of her husband, Rear Admiral Charles L. Brand, U. S. Navy, Retired, who had been President of the Society in 1944. The Award was made each year to the member of the post-graduate class who stood first in Course XIII-A at Massachusetts Institute of Technology.

Mrs. Brand set the award up for a limited time but earlier this year the Council decided to continue the award indefinitely. It will continue to be called "The Brand Award" and will be made by the Society in the name of Mrs. Brand.

The Brand award for 1959 was presented to
Lieutenant Bruce J. Wooden, USN

St. Lawrence Seaway

The reprinted article on page 535 was written before the Seaway was dedicated and officially opened to traffic. The July 13, 1959 issue of *Life* carries some very interesting pictures of the first passage from the St. Lawrence river to Chicago, Illinois of a Navy flotilla consisting of the heavy cruiser U. S. S. *Macon*, CA132 and 21 other ships.

Foreign Circulation

It may be of some general interest to note the extent to which the JOURNAL is distributed outside of the United States. This certainly does not begin to compare with the ubiquitous circulation of many periodicals but for our type of journal, where few foreigners are eligible for membership and subscriptions are entirely voluntary, we feel that these statistics are significant.

355 copies of the JOURNAL go to 39 foreign countries. 66 of these are to members distributed:

9 in Canada
8 in England
7 in Argentina
6 in Italy
4 in Portugal
3 each in Japan and the Netherlands
2 each in Brazil, Denmark, France, Mexico, Scotland, Switzerland, Thailand and Venezuela and
1 each in Arabia, China, Colombia, China, Germany, Greece, India, Iran, Korea and Norway

23 copies are exchanged with other publications. 15 of these are in England, 2 in France and 1 each in Hungary, Italy, Japan, Rumania, Russia and Scotland.

Naturally subscriptions are the biggest component of our foreign circulation. There are 266 of these which are mailed to the following countries:

66 to Russia
47 to Sweden
28 to Japan
18 to Italy
17 to England
13 to France
11 to Germany
8 to Yugoslavia
7 each to Canada, the Netherlands, Norway, Poland
6 to Spain
2 each to Arabia, Argentina, Australia, Finland, Hungary, India, Rumania and Switzerland
1 each to Bulgaria, Chile, Denmark, Egypt, Israel, North Africa, Portugal and Scotland.

Dr. Alfred J. Buchi

We have learned that Dr. Buchi, still active in managing his engineering undertakings in Switzerland celebrated his 80th birthday on 11 July 1959. Dr. Buchi's tremendous contributions in supercharging oil and gas engines are well known in The Internal Combustion Engine field and to members of the Society. Dr. Buchi is a member of the Society, having joined in December 1952.

Past-President A. G. Mumma

The Worthington Corporation of Harrison, New Jersey has announced the appointment of Rear Admiral Albert G. Mumma, U. S. N. Retired, as Vice President-Engineering of that company. Admiral Mumma served as President of the Society in 1957. He retired from the Navy in April 1959 upon completion of his term as Chief of the Bureau of Ships.

Machol Edge Index

In this issue we are using the Machol Edge Index on a trial run basis. Our decision to continue its use will depend entirely on the reactions of members and other readers. Naturally, we will not know what these are unless you pass the word to us. Our decision will be open until about 15 October 1959.

The claimed advantage of the Index is that it will increase the value of the Journal to you at a very nominal cost to the Society. The cost is not great and it will not force us to reduce the technical value of the Journal in any way nor to require an increase in dues or subscription rates. The increased value is in the facility to you of finding the article which you want to read more readily and to induce you to read more articles than you would otherwise.

If the Index impresses you either favorably or unfavorably please, without delay, give us your opinion in a letter or postcard. It is you who must decide.

Bound Volumes of the Journal

A member has placed in our hands for sale, if possible, bound volumes of the JOURNAL in excellent condition for the years 1889 (Volume I) through 1906 inclusive.

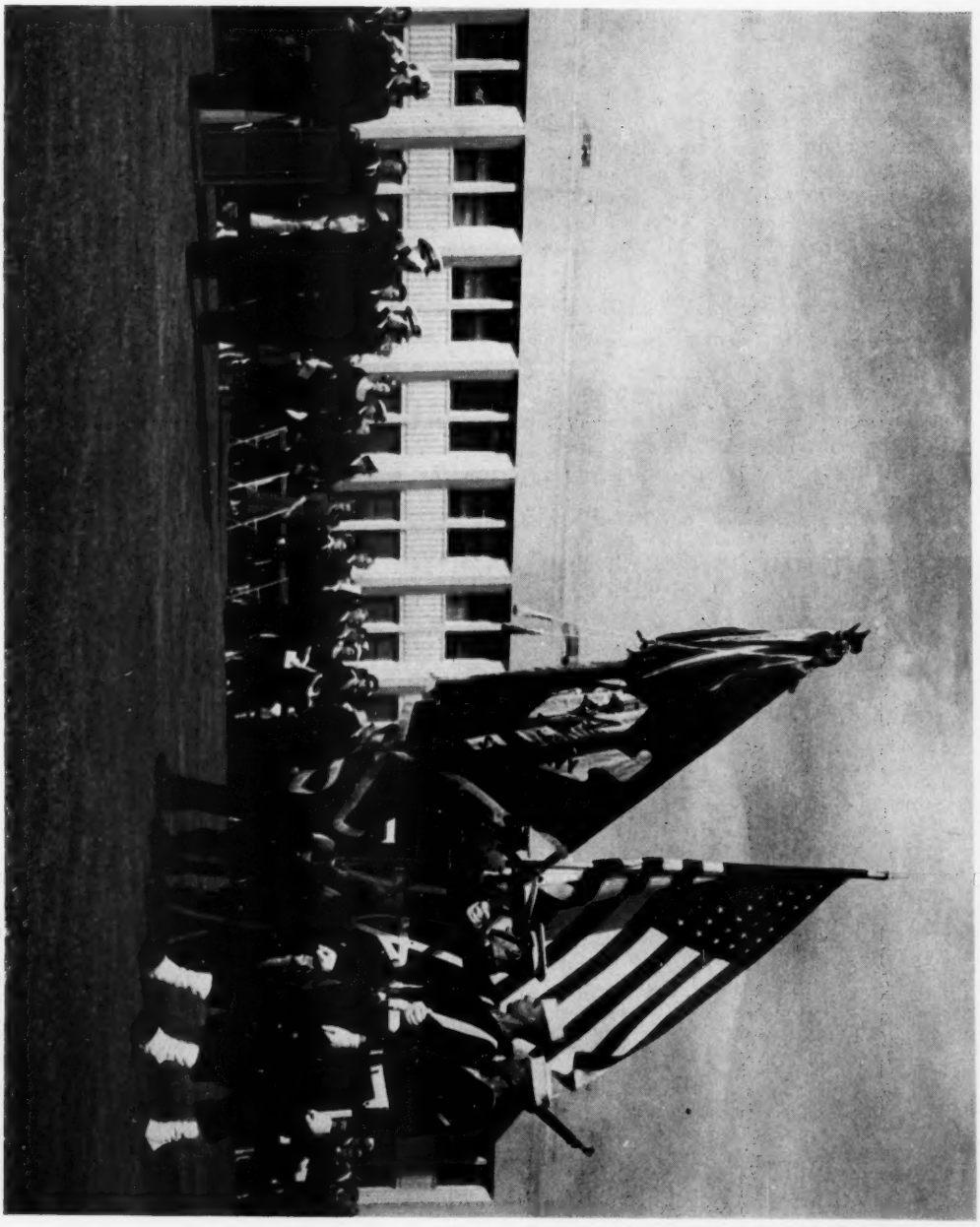
The established price of these volumes is:

1889 to 1899 inclusive	
Domestic delivery	$22.00 per volume
Foreign delivery	$36.75 per volume
1900 to 1906 inclusive	
Domestic delivery	$18.00 per volume
Foreign delivery	$30.00 per volume

The first reliable offer at the established prices which are subject to a 10 percent dealer's discount and 2 percent discount for cash, for the entire set of 18 volumes, will be accepted. Any other offer for the entire set will be considered. No offer for single volumes or for any part of the set will be considered at this time.

British Income Tax

The Society has been informed by the Taxes Branch of the British Inland Revenue, that "the whole of the annual subscription paid by members" to the American Society of Naval Engineers, Inc. "will be allowable as a deduction from his emoluments assessable to income tax under Schedule E." For further details see page 570.



Official United States Navy Photograph

FIRST DISPLAY OF NAVY FLAG

The U. S. Navy flag was publicly displayed for the first time on Thursday, April 30, 1959 during honor ceremonies for Rear Admiral Albert G. Mumma, USN, who retired from active Naval Service. Admiral Mumma was the Chief of the Bureau of Ships and President of the Society in 1957. The ceremonies were held at the David Taylor Model Basin. Shown during the review are (L to R) Vice Admiral H. P. Smith USN, Chief of Naval Personnel, Admiral Mumma, and Rear Admiral Wm. K. Mendenhall, Jr., USN, Commandant Potomac River Naval Command.

ASNE Service Academy Awards

The ASNE awards to graduates of the service academies which were initiated by the Council in 1956 were made for the fourth time this year. The President, Admiral Dolan, was able to attend each of the ceremonies and to present the awards for the Society. Photographs of these events are included in these Notes.

The general purpose of this ASNE award is to give recognition to the member of the graduating class who has distinguished himself as outstandingly proficient in engineering as demonstrated by his academic work. In each case the criteria for selection for the award and the actual selection of the awardee are entirely up to the officials of the respective academy.

The 1959 awards were made as follows:

U.S. Naval Academy, Annapolis, Maryland, on 1 June 1959

For standing highest in the combined courses in Mathematics, Marine Engineering and Electrical Engineering to—

Midshipman Dennis Walter Brezina, of Antioch, Illinois

Admiral Dolan **Midshipman Brezina**

U.S. Coast Guard Academy, New London, Connecticut, on 2 June 1959

For standing first in his class in the course of Power Engineering to—

Cadet Garret T. Bush, III of Oakland, California

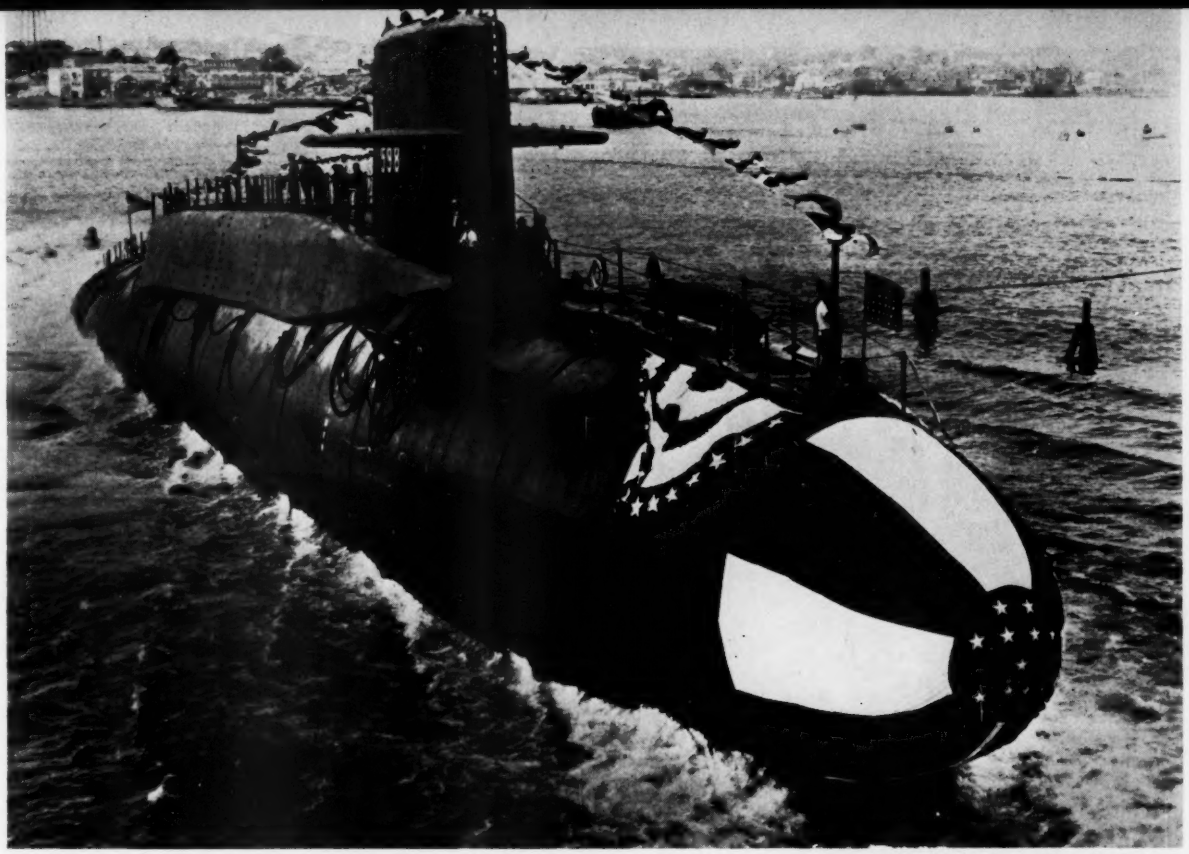
Admiral Dolan **Cadet Bush**

U.S. Merchant Marine Academy, Kings Point, Long Island, on 6 August 1959

For being the member of his class considered to show the most promise as a naval engineer to—

Engineer Cadet Frederick W. Ziegler of Woodcliff Lake, New Jersey

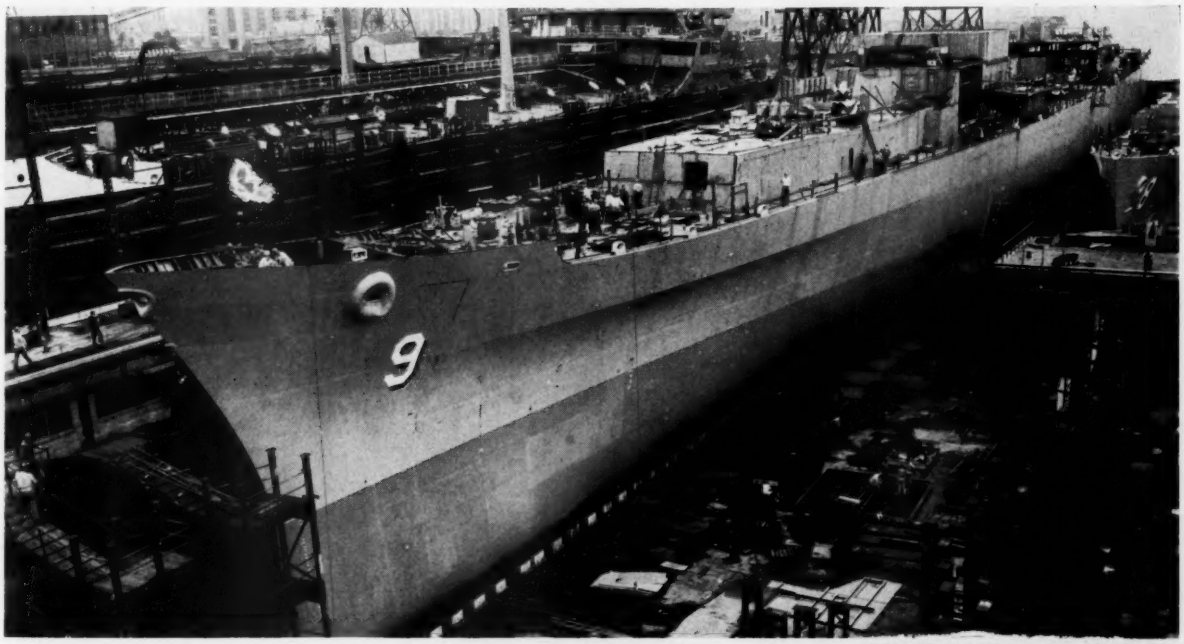
Admiral Dolan **Cadet Ziegler**



Official United States Navy Photograph

FIRST FLEET BALLISTIC MISSILE SUBMARINE LAUNCHED

The USS *George Washington*, The U. S. Navy's first ballistic missile submarine, is shown minutes after launching at Groton, Conn., June 9, 1959. The nuclear powered submarine has 16 firing tubes designed to launch the solid fueled Polaris, the Navy's 1200 miles ballistic missile. The *George Washington* is being built by Electric Boat Division of General Dynamics Corporation.



Official United States Navy Photograph

FIRST U. S. NUCLEAR SURFACE SHIP TO BE LAUNCHED BY NAVY

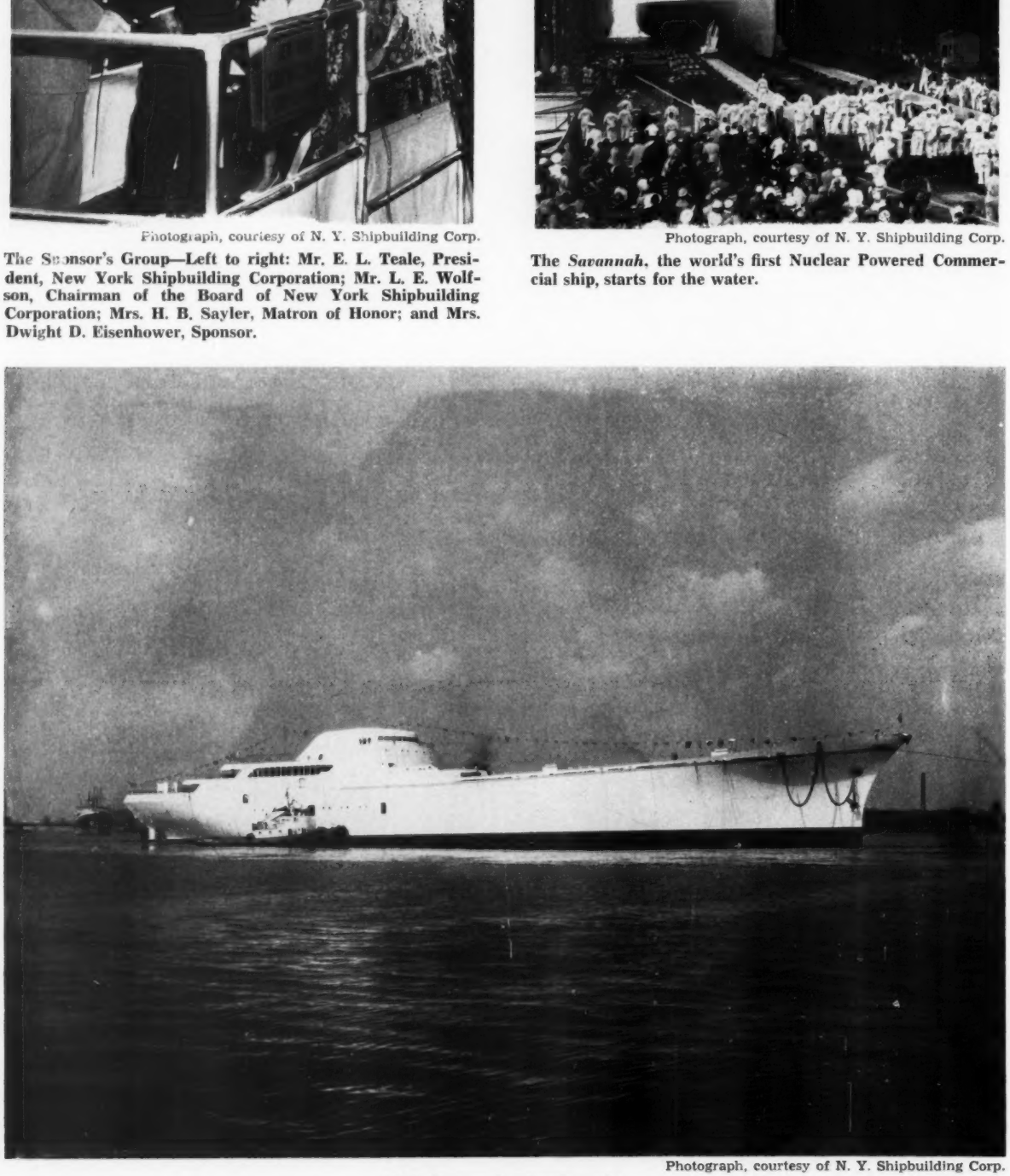
Shown in the building dock at Bethlehem Steel Company, Quincy, Massachusetts, a few days before her launching is the guided missile cruiser, USS *Long Beach*, CG(N)-9. The United States' first nuclear powered surface ship, her armament will include the Talos and Terrier missiles. Powered by twin nuclear reactors and screws, the *Long Beach* is 721 feet in length, 73 feet in beam, and has a 14,000 ton displacement. She is scheduled to join the fleet in 1961 or early 1962.

Photograph, courtesy of N. Y. Shipbuilding Corp.

The Sponsor's Group—Left to right: Mr. E. L. Teale, President, New York Shipbuilding Corporation; Mr. L. E. Wolfson, Chairman of the Board of New York Shipbuilding Corporation; Mrs. H. B. Sayler, Matron of Honor; and Mrs. Dwight D. Eisenhower, Sponsor.

Photograph, courtesy of N. Y. Shipbuilding Corp.

The *Savannah*, the world's first Nuclear Powered Commercial ship, starts for the water.



Photograph, courtesy of N. Y. Shipbuilding Corp.

N. S. *Savannah*, after Launch.

THE N.S. *SAVANNAH*

One hundred and forty years ago, on May 22, 1819, a 320-ton ship started an epoch-marking voyage from Savannah, Georgia to Liverpool, England. She was the *Savannah*, the first vessel to use steam on a transatlantic crossing. The 29-day, 11 hour voyage was successful even though the little craft could carry only enough coal and wood to permit about 89 hours of steaming spread over at least seven days.

As the *Savannah* ushered in the Steam Age in ocean travel, it is fitting that another *Savannah* should usher in the Atomic Age. After President Eisenhower signed the bill authorizing the construction of the first nuclear-powered merchant ship, he accepted the suggestion of American shipping men and named her the "N.S. *Savannah*." This was fitting, since the new ship which will bear the designation "N.S." (for Nuclear Ship) is another first, as important as was the little *Savannah* which opened a new era 140 years ago.

The project to build the N.S. *Savannah* was undertaken in keeping with the policy of the President and the Congress to foster and develop the American Merchant Marine and to demonstrate to the world the intent of the United States to employ the power of the atom for peaceful, productive purposes.

The development of the new nuclear-powered cargo-passenger ship *Savannah*, is the joint responsibility of the Maritime Administration of the U.S. Department of Commerce and the U.S. Atomic Energy Commission. The combined effort is being carried on through a joint group known as the Nuclear Projects Office in the Maritime Administration, and as the Maritime Reactors Branch in the Atomic Energy Commission. The ship was designed by George G. Sharp, Inc., and is now under construction at New York Shipbuilding Corporation at Camden, New Jersey. The Babcock and Wilcox Company holds the prime contract for the propulsion machinery with DeLaval Steam Turbine Company as subcontractor for the turbines, reduction gears, and other heavy machinery.

Building of a nuclear-powered merchant ship was first proposed by President Eisenhower in a speech in New York on April 25, 1955. Construction was authorized by Public Law 848, July 30, 1956, (Sec. 716, Merchant Marine Act of 1936, as amended) with the ship to be built by the U. S. Maritime Administration and the U. S. Atomic Energy Commission, jointly. Under Sec. 715 of the Merchant Marine Act of 1936, as amended, the ship is to be operated by the Maritime Administration. States Marine Corporation of Delaware will operate the ship as General Agent for the Maritime Administration.

The contract with the Babcock and Wilcox Company for development and fabrication of the nuclear propulsion system was signed April 4, 1957. The contract for construction of the *Savannah* was signed with the New York Shipbuilding Corporation, Camden, New Jersey, on November 15, 1957. The keel for the *Savannah* was laid on National Maritime Day, May 22, 1958, and the ship was launched on July 21, 1959, with Mrs. Dwight D. Eisenhower as sponsor.

Construction of the ship will be completed and the *Savannah* ready for loading of her nuclear fuel by early 1960. It is expected that the *Savannah* will undergo extensive testing during the Spring of 1960, and that she will be ready for unrestricted operation by summer 1960.

From its inception, it has been acknowledged that the *Savannah* itself will not attain economically competitive operation; nor is she intended as a prototype. Rather, it has been planned to utilize this "first generation" nuclear-powered merchant ship to develop practical construction and operating technology and to employ this information in evaluating and designing "second and third generation" nuclear powered ships which can attain competitive performance in free enterprise.

It is planned that the *Savannah* will be a test ship. Many special features, such as provision for extensive remote operation of components and the possibility of rapid maneuvering rates, which are not essential for proper performance of this ship-type have been incorporated for evaluation in future designs. During operation of the *Savannah*, it is fully expected that components, and even entire plant systems, will be changed, when it is indicated that significant improvements can be made.

Finally, the *Savannah* has five important missions:

(1) To demonstrate to the world the employment of nuclear power in an instrument of peace for the benefit of mankind,

(2) To bring the power of the atom into the market places of the world in peaceful trade and commerce,

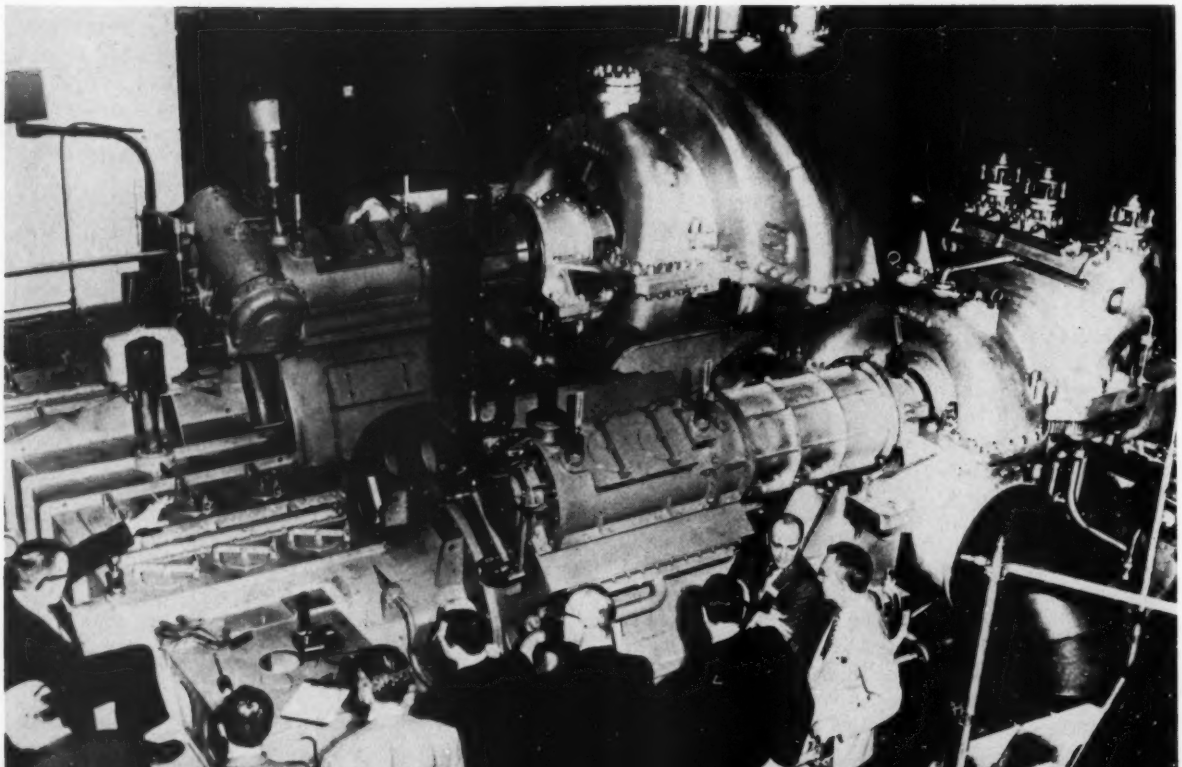
(3) To enlighten the public to the fact that nuclear-powered ships are entirely dependable and safe,

(4) To stimulate early solutions to such problems as international liability and indemnification, and, win for nuclear ships, acceptance in the world's ports,

(5) To give the Maritime Administration and the Atomic Energy Commission the opportunity for prudently assessing the possible contributions of atomic power to the progress of the American Merchant Marine in providing shipping services on routes essential for maintaining the flow of the foreign commerce of the United States.

The *Savannah's* rather elaborate provisions for shielding reactor containment, ship structural integrity, safe storage of all wastes, and the continuous monitoring of every potentially hazardous con-

dition, are results of several years of study. These designs have been reviewed and accepted by the U.S. Coast Guard, the American Bureau of Shipping, and U. S. Public Health Service, and will meet the recommendations of the Atomic Energy Commission's Advisory Committee on Reactor Safeguards. In every case, design and construction practice has followed recommendations of American Society of Mechanical Engineers, American Institute of Electrical Engineers, American Society for Testing Materials and other Technical societies. Continuing review is presently being conducted by agencies such as the Atomic Energy Commission's Oak Ridge National Laboratory and Advisory Committee on Reactor Safeguards and other agencies interested in safety of life at sea. In addition, international discussions, particularly with the United Kingdom, have already begun on an informal basis.



Shown under test at the DeLaval Steam Turbine Company, this steam turbine will propel the N. S. *Savannah* along the world's water routes at a steady 21 knots. Atomic heat will produce the steam, representing the world's first application of nuclear energy in a merchant ship. Carrying a crew of about 110, and with accomodations for 60 passengers and 10,000 tons of cargo, the N. S. *Savannah* will be able to operate for 3½ years on one fuel loading. Under normal operation, the power plant will deliver a steady 20,000 shaft horsepower, which can be stepped up to 22,000 shaft horsepower when desired.

HAROLD MANSFIELD

OUR RED RIVALS

ACKNOWLEDGEMENT

Harold Mansfield, Director of Public Relations of Boeing Airplane Company, is the author of this article. He recently visited Russia as a member of a delegation sponsored by the International Council of Industrial Editors (ICIE).
Copyright 1958 by Harold Mansfield.

I

You enter Moscow with misgivings. The thousand questions stored in your mind . . . Will they be answered? The night about you . . . Will it be friendly? The silent, big-shouldered driver of the black Zim limousine that is bringing you from the airport up the dark Moscow River into the city . . . How does he think?

Impressive facades of brightly-lighted buildings loom along the boulevard. You try out your Russian: "New apartments?"

"Da," says the driver.

"Much progress here."

"Da, da, da." You can feel the quick pride that is tongued in that triple yes. You imagine you have already touched the keyword that is moving the Russian people: "Progress."

Two and a half years ago, you pondered the speech made by N. V. Khrushchev at the Soviets' first Communist Party Congress since Stalin's death. Said Khrushchev then: "The principal feature of our effort is the emergence of socialism from the confines of one country and its transformance into a world system. The internal forces of the capitalist economy are working toward its downfall, while the Communist economy is steadily rising toward *its goal of proving itself to the world and transforming itself into a world system through peaceful competition.*"

". . . Through peaceful competition." A sober challenge and a threat, aimed directly at the industrial heart-stream of America and the West. Not just defense industry, charged with the task of exceeding Soviet ingenuity in arms, but all industry and business.

Now Khrushchev has been running the show long enough to reveal how he intends carrying out his program. Could he possibly win this race for industrial supremacy, and with it his sweeping political aims? You are here to investigate.

In the days that follow in Moscow, Leningrad, Kiev, Kharkov, between supervised tours and plant visits, you prowl the streets on your own, anxious to meet and talk with workers and citizens. You find them surprisingly friendly. Using your fractured Russian in impromptu conversations, you try to sense the mood and the spirit of the people. You form some impressions.

Russia has a serious look on its face. It is a drab, purposeful, working civilization, in open-collared shirt. Its people are proud and sensitive, self-conscious about their long isolation from the West, hurt by its scorn. They are hungry for the world's esteem, and intend to win it.

"Russians are not barbarians," says a young school teacher, neat in simple skirt and wool sweater. With a slight, quick toss of blond hair and a flick of manicured fingers she adds: ". . . as you can see."

You ask a female guide if a luxurious train between Moscow and Leningrad was not German-built before the war, which it was. She is affronted. "Do you think it's too good to be Russian?"

Somehow you feel that this psychology helps explain the daring push to launch the sputniks, the jutting of astonishing white multi-storied towers, nineteenth-century "monumental" in architecture, out of the otherwise flat, grey Moscow skyline. It helps explain, too, the ornate subway stations under the streets. Marble-columned, sculptured and chandeliered, they appear at once an effort to outdo the splendor of the czars, and an installment on a future-day communist millennium.

Communism exists on the basis of a great hope, a hope kept alive by show of progress, and contrasted sharply with a depressed people's past. The people go along with the objective, little complaining if it is still out of reach. They have set out on an enterprise and intend to prove they can make it go. They have lived with the system long enough now that most take it for granted, much as Americans take theirs for granted.

But the communist "millennium" is a dream. The country is poor. The government knows this and has had to take things in their order, first heavy industry, next trucks and tractors, then busses and subways for public transportation, now apartments. Everywhere you see new apartments being built like mad, thrown up by brigades of mainly unskilled men and women; uninspired, square-walled masonry buildings, each a replica of the last.

By the thousands, the people are moving into these apartments from dingy places on back streets. They still offer only minimum living. You suddenly realize why they looked so dazzling bright that first night. No curtains. Frugally furnished, they house often two or three people to the 10- by 16-foot room. But "they're much better than what we had," the occupants tell you.

It's the progress that keeps the people going. Press and radio recite it daily. Colored charts in public buildings display it. Progress toward a goal. And always a promise. Tomorrow, refrigerators and automobiles.

You ask a worker, unshaved and in crumpled clothes: "Do you think a man with a five-room house, a car, a television set, electric refrigerator and washing machine is rich?"

"Da," he nods.

"Do you think the average American worker has these things?"

"I don't know."

"He does. Do you think the Russian worker will have them?"

"I don't know. We hope."

You ask another, better dressed, the same question.

"Da," he answers. "We will catch up with America."

II

In school, in the factory, at the art exhibit, *work* is touted as the basic virtue in Russia. The brass ornament on your hotel room desk consists of three men bent low and pulling a load. The sculptor has made them appear to enjoy it.

Waiting on the street, you talk with a man about jet transports and things. "Are you pleased with Russia's progress in industry and science?" you ask.

"Naturally."

"Why?"

"Because it makes more work."

By the swan pool in Gorky park you ask a keen-looking lad what field he wants to enter when he grows up.

"Science."

"Why? Because of the high pay? Fame?"

He wrinkles his forehead. "Because it is useful," he says.

On the deck of a Sunday afternoon boat up the Moscow River you slide onto the bench beside a man in work clothes, taking a bundle of berry bushes home to plant. He is a skilled mechanic in a nearby factory. You talk with him about his work. "Do you get paid more every year?" you ask.

"Not necessarily. We get paid more when we do more and better work."

"Do you think this is a good system?"

"Da. Good."

A big, brightly-colored factory poster shows a vigerous youth pointing to a minute on the clock. "Watch the working minute!" he cautions. "Time is the people's wealth." A chart shows how much steel, coal, sugar, housing is produced "in our country" per working minute.

"In *our* country, everyone works," the people tell you with pride.

Then they ask about your country. "Is it true there are four million unemployed?"

You explain: "At present the prices on some things have gone rather high and people are not buying as they did. Wages and prices are high. But the state pays those who are out of work."

"How much does a skilled worker make in America?" asks his Russian counterpart, who earns 1,200 rubles a month—or 60 cents an hour, figured at ten rubles to the dollar. (Tourists are given ten rubles to the dollar. Official exchange is four to the dollar, but based on prices ten to one seems nearer correct.)

"In America he gets $2.50 to $3 per hour; maybe more," you say.

He is thoughtful, possibly incredulous.

You are thoughtful. You begin to see the problem in an unwelcome light.

Khrushchev spoke of the communist economy "proving itself" and "transforming itself into a world economy through peaceful competition." This competition, obviously, is to be in the world market. On one side is America, with its highly priced man-hour. Up to now it has made good that high cost, by ma-

chinery and tooling and mass production. But here you find Russia setting up with deliberate care the same mass-production technique, with low-cost man-hours. You quickly decide America will not relinquish its high pay, because it makes purchasing power. You see a challenge of immense proportions looming before United States industry: How to match a coming giant rival whose ideal is output, not pay.

Before your eyes, you can see the seeds of the great contest being planted. Hotel lobbies and dining rooms are teeming with foreign guests—Asians, Africans, a South American talking business with a Russian host across champagne and caviar. Seeds of peaceful competition.

A strange thought crosses your mind: a future Russia emerging from the iron curtain and America withdrawing behind the dollar curtain, priced out of the market, left trading with itself. "Could it be?" you ask yourself.

You meet a young man from West Africa, jet black, intelligent of speech, a student. He has just visited China, watched the huge anti-American rally in Peking. He is touring Russia and western Europe. "I'd like to see America," he says, "but it costs too much."

"A round trip flight from London to New York is down to $450 now, economy fare," you tell him.

"But it's the hotel, the meals, the living costs," he says. "I can't afford it."

America's problem.

You consider an out. Soviet state-owned industry may fail to prove itself; may never be able to produce an equal product for less money. American ingenuity is too much for them. Or is it?

It's time to go into some Soviet plants, talk to the directors, the engineers, the trade unions. See for yourself how they're doing. You set out.

III

The spirit of the Russian industrial worker does not have the airy exhilaration of freedom, but it has the determination of grim reality: "There's a job to be done and it's up to us to do it."

It is a spirit that has had a frightful past: First the czarist's "Work, you devils, work." Then the revolutionist dictator's "Work with us, or Siberia!" Now the march-words, "Together, workers, work." It is the song of a new Volga boatman, with the boatman owning the boat.

At a machinery plant in Moscow, you enter a dark hallway, emerge to a sawtooth lighted factory area, dirt floored in part but orderly. Unlike the old Volga days, you see no line of men pulling together on a rope, but you quickly learn that collective discipline is the system, though each man tends his own machine in modern plant fashion.

You spot a chart on the wall. On it are listed the names of men and women in the shop. After each is a number—the man's "social obligation" in units of work. Squares are filled to show his work performance, with a percentage over his quota.

"How do you reward them for going over the quota?" you ask the manager.

"Extra pay."

"And if they fall behind?" You find there is more to the system. Another chart with the same layout shows the weekly quota, called the "plan," for the shop itself. Chalked in adjoining columns are the shop's actual performance and percentage over plan. The shop's record is compared with other shops. Elsewhere, the record of whole departments is charted, and that of the plant itself, compared with a national plan. It is one huge, systematic, production competition, man against man, shop against shop, department against department, plant against plant. Bonus money is provided for the individuals, shops and departments that make the best record. At the end of the year the plant itself gets a bonus to distribute if it exceeds its plan.

Back to the worker who is not fulfilling his "social obligation," you find that his shop-mates, his department, and his whole plant take an interest in bringing him into line. He is holding up their own chances for a bonus, their own record for exceeding the plan. The star worker, on the other hand, is as popular as the star on a football team. The team doesn't want to lose him.

You marvel that communism has taken free enterprise's strongest drives—competition and incentive—and put them to work on an individual and group basis to an extent never dared by free enterprise.

You speak to a guide about this. "I see you are making great use of competition," you say.

"Nyet," she replies. "We have no competition."

You are baffled. Then you discover there are two different Russian words for competition. The one you have beeen using—*konkuryentsiya*—means "rivalry," with a capitalist connotation—a bad word in Russia. The one they use—*soryevnovaniye*—means also "emulation." This they approve.

The incentives in this socialist competition are negative as well as positive, you find. You talk with the editor of the plant paper, a heavy woman and every ounce a communist. The paper is employee-run but generally sponsored by the trade union. Enthusiastically, the mother-editor explains the paper's purpose: "To criticize the work of workers and engineers, so they may be ashamed of their work and improve; to criticize the chiefs if they are not fair; to publish production plans and new ideas; to tell about the best workers in the factory so others can emulate them."

Criticism by name in the plant paper, you learn, is only part of the grim process of collective discipline. First step is reprimanding the individual before his friends. A later step, if necessary, is bringing him before a public opinion court. Removal to a lesser job, or "in rare cases," dismissal, may follow.

The head of the union, who is present, explains that

the union is as anxious as the management, or "administration" as they call it, to bring forward production. You can see why. The union is closely knit with the Party, which set the objectives in the first place.

"Is union membership voluntary?" you ask.

"Yes. Voluntary. But ninety-nine and nine-tenths per cent belong."

"Does the union ever strike for higher wages?"

"Strikes are prohibited."

IV

The director's office in the Moscow plant you are visiting is a plain upstairs room with a desk at one end and a long table. The high window at the end has heavy, dark-blue drapes, edged with tassels. Huge on the side wall is a portrait of V. I. Lenin, looking down half sternly, half benignly, as though saying, "Remember what I taught you, boys, and you'll do fine." A man hurries into the room with an arm-load of red baize cloth to cover the long table and you know you're in Russia.

The deputy director is in charge in the director's absence. He is thirty-eight, with loose-combed hair, a casual but affirmative manner. He is distinguished from the rest by his necktie.

The plant director, he explains, works under an administration under the district economic council. He takes his plans there for approval, but he has the responsibility for buying his own materials, hiring his people, and negotiating the sale of his products. He is expected to meet the production plan that is established for the year, and to make a profit.

"And what if you don't?"

"We'll probably get moved to another job."

He explains that most of the workers are paid by the piece, rather than by the hour. Their pay ranges from 600 to 1,820 rubles per month. On the average they make 930 rubles per month. This would be $93 at 10 rubles to the dollar.

The deputy director says his own pay is 3,000 rubles, plus bonuses earned for "exceeding the plan."

"How did you get the job?" asks a member of your party. "Marry the boss's daughter?"

He laughs. The government interpreter, loyal communist, takes the opportunity to quip: "Only in your country does that happen." The deputy director says he was graduated from an institute, went into the technologists' department, worked up to chief engineer and this.

Employee wages are established in an annual agreement with the trade union. Someone asks the executive, half jokingly, "Do you ever wish you didn't have a union to deal with?"

He doesn't smile. "The unions are helpful," he says.

"But what if the union and management disagree?"

The government interpreter looks around indulgently and explains: "They don't disagree."

Another asks: "What is the basis of wage increases?"

"Productivity. Advancement is on personal ability. General wages go up as productivity goes up."

You find the same system prevails in other plants you visit. "It's the production that pays the wages," they tell you.

You reflect, confusedly, that you have heard management in America make the same case that labor is making in a country where labor wears the hat.

When you wonder, at times, why the workers are not squawking to high heaven about wages, you remember the phrase "social obligation." In their view they are working not just for themselves. They are working together for a goal—to build Russia. "We work half for the present and half for the future," they say. Half to build their own standard of living, half to make the red star the great light of the world. To do this they know they must work to surpass America in all things, but most of all, in industry.

"Do you really think Russia can match America in production?" you ask in Moscow, Kiev, Kharkov, Leningrad.

Says a laboratory assistant: "Da. We are behind you now, but our tempo is greater. That means we will overtake you."

A university professor: "Da. Already we are nearly up to you in output of some things: milk, woolen cloth. We'll reach your standard of living in 10 to 15 years. . . . Maybe faster."

A skilled worker: "It is possible. In ten years we should catch you."

A store manager: "Da, but it will take a long time."

An architecture student: "Ten to fifteen years."

A young factory worker, studying nights to finish his tenth grade: "Da, we'll catch up if you don't interfere." He means if America doesn't interfere by war. Everywhere the people tell you they want peace. But they fear America.

A student of history, candidly: "I don't like Communism. I don't like capitalism. I like freedom. But Russian industry is coming up fast. Five years, Russia will produce as much as America."

On a flight between Minsk and Kiev, you sit beside a young jet pilot of the Soviet Air Force, relaxed in a gray leisure jacket made of kapron, the Russian nylon.

"Do you think your scientists will get a rocket to the moon before the United States?" you ask him.

"Sooner," he says, with a polite but confident smile.

"Think Russia will put a man on the moon in ten years?"

"Earlier. Between five and ten years, we will do it." You sense the quiet cockiness of young Russia. You ask the familiar question: "Do you think Russian industry will produce as much as America in five or ten years?"

"More than America." he replies.

You think of the great contrast between Russian living and American. It is inconceivable that they could build up their total economy that fast. "That

will be good for the Russian people if they can do it," you say.

But you know, too, that it will also pose a problem for America—in the world market.

V

Opinions differ as to timing, but not one Russian you have talked with believes his country will remain behind America industrially. Most, like the young jet pilot, believe they are already leading in science. In fact, you can recall a good many Americans at home who would grant this, though you believe it to be true only in limited fields. How has the Soviet Union achieved this point of progress? How did it successfully get off a sputnik while others slept? Except for the sputnik, what you have seen in Russia so far has been short on originality. You wonder if scientists educated under communist dogma can have the imagination to produce new scientific discoveries. You want to learn more about what motivates these men.

Loitering in the main hall of Kiev University, you meet a research psychologist, a man you think should be qualified to discuss this point. "What inspires the Russian scientist?—what make him try to discover new ideas and put them to use?" you ask him in his cluttered laboratory office next day. "Is it the money he can make, the hope of a Lenin prize and fame, love of his country, or what?"

The man across the desk has intent eyes, a lean face, and needs a shave. You are alone with him, embarking on deep waters with your frail Russian, plus his fragments of English. He leans toward you, interested: "It's all of these," he says, "but these are not all. These are not the main factors." He lays out a finger. "First, our scientists are free."

"Free? How do you mean free?"

"Free to work on things they want. If you have a new idea, you tell your superiors. If they think it is a good idea, they will say, 'Go ahead and work on it.' You are given the equipment and the facilities."

"And if they aren't interested?"

"You have to try again." He continued: "I am free to experiment on what I want. My colleagues are free to work on what they want."

He put two fingers on the table: "Second: the Russian people love the scientist."

"Why?"

"They are servants of the people. They have a high and respected position. Third: Their security is provided. They are secure on account of money."

"You mean they have good material comforts."

"Very good. But this is general: You must understand. Our people are a free people."

"The Russian *people*—free?" It is more than you can swallow, but you are polite and let him continue. He leans closer.

"My mother and father were farmers in the Ukraine," he says. "They can't read or write. I am a scientist. This is what I mean by a free people."

"Free to achieve, to go to a higher position?"

"Da. Also free from exploitation. A Russian is free in his capacity and ability. This freedom is the general factor—the chief factor that inspires our men of science." He adds: "I should have said first of all, we have general education. All are equal in possibilities."

You begin to see how the very things America credits for its great progress, Russia is adapting to its ends. Education and opportunity. You pursue your original question: "But you agreed the desire for money, fame, and love of country were each factors. Which of these three is most important?"

"We are talking openly, freely," he answers. "Love of our country is first. For myself, I do not think about money. For my friends in science, money is not the main thing in their thinking."

You say: "In America, I don't think the scientist is working mainly for money either. He works because he wants to discover new things, get more knowledge, learn new things. Only those who earn the least, work primarily for money."

He nods vigorously. "It is the same in our country. Only those who earn the least."

"What about wages in general. Do the unions ask an increase each year?"

"The government decides," he replies. "If I ask for myself, I may ask too much. It would make prices too high. We do not want inflation." He adds: "One day the ruble will be worth as much as the dollar."

"You think so? When? Ten years? Fifty years?"

"That's hard to say. But it will come."

VI

Up to now, America has been the shining model before the world's eyes. Russia wants to be that model, so people and nations will be attracted to communism. It is easy to see why Russia has set as her main goal to beat America in the economic competition.

The strange contradiction is that it is the nation whose very traditions and manners Russia seeks to warn her people against, which has become the model she seeks to emulate. You think about that. Suddenly it doesn't seem so strange. You remember your puzzling encounter with the two different meanings of "competition" in Russian. The accepted word for it means emulation. It's true, you reflect, in most any competition the contender begins to emulate the successful techniques of the champion. How else can he match him? You know it has been happening for years in design and invention. There is a joke in Russia, that the country's most successful inventor is Comrade Reguspatoff (Reg. U. S. Pat. Off.).

There is other evidence of emulation. The children, better dressed than their parents, the hope of the land, choose English language study four to one over other foreign languages. You ask some of them why.

"Because it will be the most useful to me," one boy tells you. Says another: "Because America is best in technology."

In one of the schools you visit a beginner class in English, composed of fourteen-year-old girls and boys. You mention you have a daughter about their age. Two girls in pigtails step up shyly and brightly curtsy. Carefully one of them articulates: "We wish to correspondence."

The Russian people like Americans, despite all the propaganda against them. Many tell you they would like to visit your country, but few believe they will ever get the chance.

Managers of enterprises say they want to buy American products. "You have more than you can use. We have shortages of everything," they say. "We should trade with each other."

Russians like American music. University students want to buy American suits and shirts from tourists, "because they have style."

There is even something more subtle that the Russian finds attractive to him in Americans. One guide explains it simply: "They smile."

With more tourists, more trade, is there not hope Russia will also accept new ideas and ideals? You wonder. You ask a devoted communist: "Do you people think Marx's doctrines must apply to all time? Conditions change. Do you re-examine these doctrines in light of new conditions?"

"Yes. We re-examine them."

You are surprised, a little shocked, at the answer. You hadn't expected it. Yet you have seen how these people have adopted practices foreign to the original concept of communism—"from each according to his ability, to each according to his need." Competitive incentives, profit, greater freedom of individual opportunity, private ownership are examples. You meet a family which is buying its own home under a new Moscow plan—borrowing money from the government bank and paying it back over a period of fifteen years. You learn that forty million Soviet citizens have private deposits in savings banks. You become fascinated with a speculation:

Suppose Russia were to achieve her goal of full production: Would she not have to adopt more western business methods just to keep the bustling commerce straight? Would she not have to go still further from Marxist communism, still nearer to Western methods, even though she retained government ownership, as friendly countries do to varying degrees? Instead of the present queues at government shops waiting for a few shirts and shoes, would there not be need for advertising to attract buyers? To stimulate sales, would there not be need for credit buying? Wouldn't bank accounts and checks be necessary to simply handle the money traffic? You want to talk with some bank officials about these things.

VII

When you step into a Russian savings bank, an institution rapidly growing in popularity, you think you might be in a small U. S. post office. There is the writing counter against the wall, and across from it two or three attendants' windows. Behind the partition, some women are sorting deposit slips in a shallow wood box. You watch them do their addition on Chinese abacus counting frames, adroitly clicking the beads of the ancient devices that you have also seen used in all the stores.

The manager of the bank, a man in his mid-thirties, unharried, accommodating, invites you to the back office. You feel that you have been here before, and then remember it is an old farmhouse kitchen you are thinking of, with its square-legged board table in the center. The manager apologizes for a shortage of chairs, and himself sits on the corner of the table. A government interpreter explains the intricacies of soviet banking, the six types of institutions: agricultural, state, communal, industrial, foreign trade, and savings.

You learn there is a crude approach to the use of checks, when one industrial plant writes a note to the bank which keeps its funds, asking that a certain amount of money be transferred to a bank in another city and put in the account of a plant there from which it has purchased some material. You get the manager aside.

"In the future," you say, "Russia hopes to be producing plenty of things for everyone. When that time comes, won't you need things like personal accounts at banks and credit accounts at the stores, and checks to pay for goods and services?" It is a little involved for your Russian. You repeat the question. The official interpreter hears you and comes over. You would rather have talked privately with the banker, but you put the question to the interpreter. She gives it a little laugh of inconsequentiality and turns to another man's question. Later you try it again. Finally as the visit is breaking up you insist you'd like to know the manager's opinion. She asks him. He looks at her, then at you.

"We don't have need for these things now," he says. "When we have communism,"—they always speak of communism as something in the future rather than at present — "we will need neither checks nor money."

That ends the discussion. When the wall of dogma appears, communist thought will not attempt to penetrate it. But you can see clearly the contradiction. The trend in Russia is going precisely opposite to the trend planned toward pure communism. You see it further when you visit a large state bank, a more imposing institution with a long row of cashiers clicking the beads of their abacuses, but with modern bookkeeping machines behind, and a mahogany-furnished executive office, suitably adorned with portraits. The manager asks eager questions about banking practices in America.

Business methods—even government business—have only started to make the improvements that Russian science and production have been making in recent years. The distance between the Chinese counting frame at the bank and the electric computer in the Soviet science laboratory is typical of the glar-

ing inconsistency between the country's forward drive and the cumbersome methods of communism that are dragging it back. Clumsy office methods and procedures, the bureaucratic ladder that must be climbed for policy decisions, delay, dogma and dictation, are heavy fetters on a people's push toward progress.

But Russia is getting wise to these faults. Trade with the outside world will open her eyes, sharpen her practices. To now, America has been reaping a competitive advantage from the backward cumbersomeness of communism itself, the high "overhead" cost of its super-government, the ponderosity of government control. Because of this, Americans have often wrongly assumed that Russia could never do what it says. But the streamlining is bound to come. As an example, Russian plant directors say the recent decentralization of industrial ministries has greatly speeded the process of decision.

Meanwhile America has its own trend to "big government." Even now, you reflect, there isn't too much difference between the length of the list of ministries and policy-forming institutes in Moscow and the list of agencies and committees in Washington. Different names. America is not immune to the problems of big government.

VIII

There is ample evidence that Russia is pushing resolutely Khrushchev's program to "prove communism to the world" through peaceful competition.

What of his other contention, borrowed from earlier communist theorists, that meanwhile "the internal forces of capitalism are working toward its downfall?" Can you merely pooh-pooh this brash claim? Viewed from the distance of Soviet Russia, you can see the dangers inherent in America's success. The spoil of success is indulgence. You can't for the life of you see how America can long keep its world leadership in the "peaceful competition" if it indulges the luxury of waste, the luxury of half-hearted effort, the old-style luxury of paying tribute to any group which can exact it through power, the bitterly illusory luxury of inflation. Not when Russia is living and breathing cost control.

Between acts of the opera in Kiev you follow the crowd downstairs to the drawing room where refreshments are being served. You stand in line for a thirty-cent dish of ice cream. You watch with utter fascination the apron-clad girl who is dishing it out. Each dish goes on a little balance like the one at the pharmacist's. She dips up a scoop of ice cream and puts it on the balance. If the balance is high, she adds a trifle, lightning-like because of the waiting crowd. If it is low, with one deft twist of the wrist she flicks off the half teaspoon that will bring it into balance, and returns this to the container for the next serving.

You look about at the happily chattering people. Other than you, no one in the room considers the precise weighing process in the least odd.

This balance, you can't help thinking, is emblematic of Russian effort to make cost and output meet. You have seen it in the whole Russian economy, the fight to build without inflation. You might say it is emblematic, too, of the counter scale of a new, sharp dealer down the street of nations. He is in poor quarters now, but working and saving for the day when he can buy out the rich store on the main intersection. The big store owner with his Cadillac has "had it so good" that he has not much worried about the new competition. But lately he has begun to wonder; ever since the other storekeeper shot a sputnik into the sky and began to attract customers.

The little ice cream balance, you think further, betokens a balance of power in the world: The forces of communism against the forces of freedom. Two societies basically antagonistic, though simulating each other in surprising, unacknowledged ways. Between them, there is a balancing of military power and of advancement in military weaponry: atomic stalemate. The more frightful the weapon becomes, the deeper the stalemate, because of mutual fear not so much of the other country as of the weapon itself.

You have seen, growing out of the stalemate, Mr. Khrushchev's new plan to sell communism to the world. The pharmacist's balance looms larger, filling the frame of your thought. You see everything that the communist world does and everything that the free world does as adding to one side or the other of the balance. You see everything that either fails to do as substracting from its side of the balance.

You realize, as never before, that your country is being weighed in the balance. It has no self-perpetuating heritage of superiority. It must prove itself, year to year. It stands challenged.

Is the system of freedom and equity answering the challenge? To do so, must it not cite for its people a goal of its own—to paraphrase Khrushchev: "the emergence of freedom and equity as a world system?" Must it not sacrifice selfishness and work for its goal, as Russia has taught her people to work for theirs?

You come back to America, land of the free, to find Americans taking riotous advantage of that freedom. You realize as never before that freedom requires self-discipline. Nothing less can match the discipline of a communist regime.

And how is this related to peace?

Because the road to peace is not paved with the unturned stones of idleness, selfishness or complacency.

Because atomic stalemate still leaves the Soviet Union free to gain the balance of world power by the route Mr. Khrushchev has announced.

Because, if communism gains the balance of power by any means, the peace is lost. Then freedom's great struggle will still be ahead.

On the other hand, for America to stay in the peaceful competition will mean that it will have to improve, and that the Soviet system and ideology will

have to improve, through competitive emulation. If this happens, the great cause for conflict—the conflict of beliefs—may be removed and replaced by a better understanding, stone by stone.

Industry, labor, all America, have their part to play. Your sense of the unsolved problem shouts within you that Americans must work for their own future.

But not just that.

They must get interested in something besides themselves. In other countries. In the world. In people. Even Russian people. In the two little girls who "wish to correspondence."

The girls are fourteen now. In ten years they will be women. The ten years in which Soviet Russia says it will "catch America." And after that . . .?

A 105 ton reactor vessel, in which an atomic "fire" will be kindled to drive the N. S. Savannah, world's first nuclear merchant ship, has been installed in the ship's hull. Climaxing an intricate, carefully planned operation, the sealed pressure vessel, 28 feet high and 9 feet in diameter, was hoisted above the ship and lowered through a 13-foot, 6-inch hatch in a spherical "containment" shell. Together with the reactor vessel, all nuclear components of the propulsion system, which is being supplied by the Babcock & Wilcox Company, are being erected amidships within this 35 by 50-foot protective chamber. Placement of the reactor vessel within the one-eighth of an inch margin allowed for error was complicated by the 3 degree launching angle at which the hull rests on her way. This step completes erection of the propulsion system's heaviest components. Previously installed were two steam generators 20 feet long and 15 feet high, and a pressurizer 5 feet in diameter and 18 feet long. Although all components installed thus far weigh a total of 182 tons, they represent only about one per cent of all the parts that will be positioned in the containment shell by early 1960. The manufacture and installation of remaining nuclear propulsion equipment is proceeding on schedule, B&W officials report.

—from PRESS RELEASE
The Babcock and Wilcox Company

ROBERT TAGGART

SPECIAL PURPOSE MARINE PROPULSION SYSTEMS, PART I

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INTRODUCTION

In years past the paddle-wheel served as the primary means of mechanical ship propulsion. After years of successful service it was finally supplanted by the more efficient and reliable screw propeller. Although this latter propulsion device is almost universally used to move ships through the water it does have certain limitations.

The screw propeller is not particularly ideal for maneuvering a ship. When backing and filling it works in a very inefficient speed range, thus calling for skillful operation and great demands on the propulsion machinery. Its essentially unidirectional thrust does not readily lend itself to using the screw for steering despite the fact that turning torque on the ship can be obtained by varying the thrust of opposing propellers on multiple-screw ships.

The screw propeller is very inefficient when operating at high thrust loadings and low speeds of advance. It has a single optimum operating efficiency at a set pitch-speed-power-rpm relationship which is inflexible. The screw requires a fixed submergence for efficient operation and is subject to damage in cluttered or shallow waters, and finally, it is definitely not recommended for land propulsion of amphibious vehicles.

In some requirements for marine vehicles these features of the conventional screw propeller militate against its use. Hence it has been necessary to either modify the screw extensively or to develop some other type of thrust-producing device to fulfill the specified functions.

This article is devoted to such special purpose marine propulsion systems. These systems can be called neither novel nor unconventional. They are engineering designs developed for a particular purpose. It is only when their utilization is attempted in a service for which they are neither designed nor suited that they become unconventional.

THE CONTROLLABLE-PITCH PROPELLER

There are many types of ships which operate under conditions where maximum efficiency is desired under two or more operating conditions. Tugs and trawlers, for example, must operate efficiently both free running and when towing heavy loads; submarines must operate efficiently both on or near the surface and when deeply submerged. Other ships are equipped with propulsion plants which cannot be reversed or in which a reversing mechanism would be inordinately expensive.

The earliest solutions to this type of problem were begun many years ago. When screw propellers first were used as auxiliary power on sailing ships it was desirable to remove the resistive forces of the dragging propeller when the ship was making its way under sail. Some inventors solved the problem by devising rigs to unship the propeller when under sail. However, others designed blade feathering mechanisms which were the first steps toward the controllable-pitch propeller.

One of the first of these early inventors was Bennett Woodcroft of Manchester, England. In 1844 he patented a controllable-pitch propeller for *"varying at pleasure the angle of screw propeller blades with the axis on which they work, according to the varying circumstances of wind, current, tonnage, and the other conditions affecting the action of the motive power in vessels."*

Woodcroft's mechanism was quite simple. The bases of the blades were short, cylindrical shafts which were fitted into the hub and were free to pivot. To each blade was attached a short eccentric lever which in turn was pinned to a collar mounted around the propeller shaft forward of the propeller. This collar could be moved fore and aft by a bell-crank arrangement operated by a push-rod from the deck thus altering the propeller pitch.

This idea, although unique, was not entirely new. Robert Hooke had demonstrated a wind velocity indicator to the Royal Society in 1683 which had a similar controllable-pitch feature, and John Millington had proposed such a device for a ship propeller in 1816. Woodcroft's device suffered from the exposure of the operating mechanism to salt water, but otherwise had some of the basic features found in pitch control mechanisms in use today.

A variant of this idea was proposed by Thomas Oxley of London in 1845. Rather than changing the pitch to alter thrust for a given speed, Oxley proposed changing the propeller diameter. His arrangement consisted of a series of telescoping blades which were actuated by racks driven by a central pinion.

Christopher D. Hays of Bermondsey, England, patented a quite modern form of controllable-pitch propeller in 1845. The pitch control mechanism was completely contained within the hub. Levers which turned the blades were actuated by a control rod running through the center of the propeller shaft. Hays included two additional features of interest in his patent. By means of a rack and pinion arrangement the entire propeller assembly could be raised out of the water for overhaul. When the blades were feathered he also provided sliding shutters on either side of the propeller aperture which would fair in that part of the ship for easier running under sail.

In 1848 Joseph Maudsley of London patented another type of pitch control mechanism. His blades were attached to segments of spur gears which meshed in such a manner that rotation of one blade caused a corresponding rotation of the other. The gear of the forward blade was fitted with a swivel joint to a sliding collar on the propeller shaft. This collar was moved in a fore and aft direction by a bell crank and actuating rod in a manner similar to Woodcroft's earlier design. Unlike Woodcroft, however, Maudsley completely enclosed his pitch-changing mechanism in the hub.

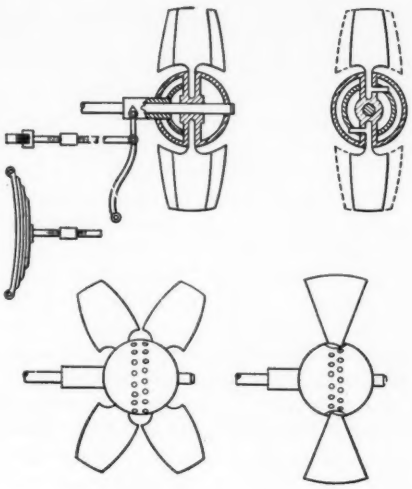
Robert Griffiths of Le Havre, France, proposed an interesting pitch control mechanism in 1849 which was basically similar to Woodcroft's 1844 patent. However, the mechanism was contained within a spherical hub and the blade actuating levers were replaced by a hemispherical inner shell. The most interesting feature of Griffiths' proposal was a leaf spring mounting for the control rod. If this propeller should overspeed this spring would increase the pitch, thus loading down the engine and returning the speed to normal. A propeller of this type was installed in the *Merrimac* prior to her encounter with the *Monitor*.

Bennett Woodcroft was issued another controllable-pitch propeller patent in 1851. The mechanism of this new propeller was completely enclosed within the hub. A concentric sleeve around the drive shaft actuated a pair of worm gears which in turn rotated worm wheels mounted on the blade pinions. A somewhat similar arrangement was also proposed in which a rack ran through the center of the propeller shaft and drove the blade pinions.

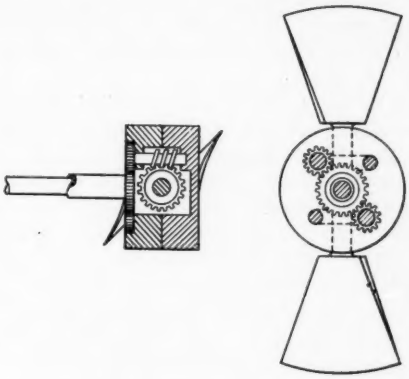
The pitch control mechanisms proposed by Woodcroft, Hays, Maudsley, and Griffiths are shown in Figure 1.

When the steam turbine was introduced, the desirability of changing the direction of thrust by reversing pitch again became apparent. This essentially irreversible power plant required the addition of a reversing turbine to stop and back the ship. The astern turbine not only reduced the efficiency of the ahead turbine but could apply only a limited amount of torque for backing down. At reduced speeds the early turbines could have been employed more efficiently if the propeller pitch could have been regulated. But in spite of these indications for the need for a controllable-reversible-pitch propeller, astern turbines were almost universally installed in steam turbine-driven ships. This can be taken as a definite indication of the lack of reliability in early pitch control mechanism designs.

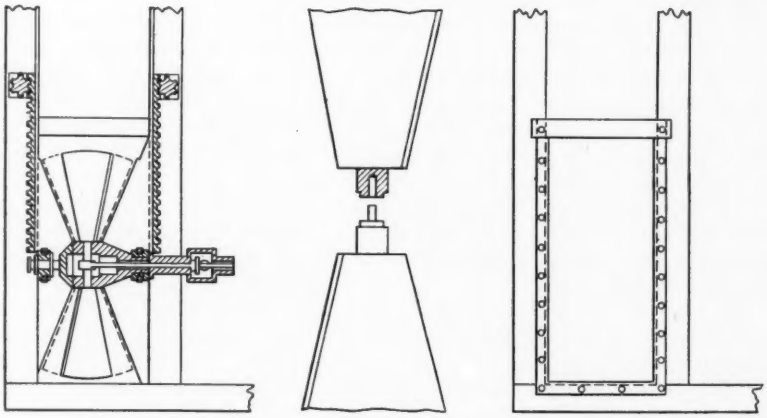
Astern turbines are not practical when a large



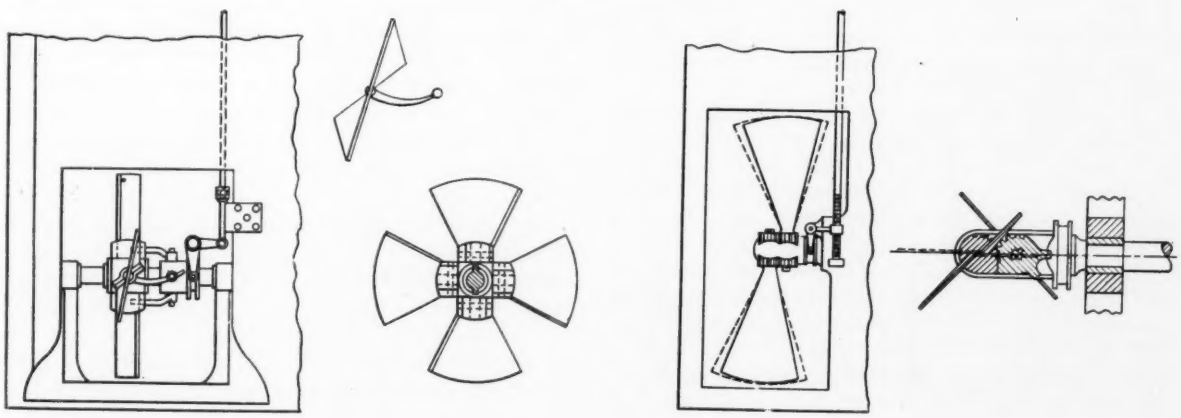
Griffiths 1849



Woodcroft 1851



Hays 1845



Woodcroft 1844

Maudsley 1818

Figure 1. Early Propeller Feathering Mechanisms.

marine gas turbine is employed for main propulsion drives. Windage losses would be excessive when idling and overheating would be unavoidable. The recent advent of this form of prime mover has spurred the seach for better controllable-pitch mechanisms.

Similarly, the diesel engine has had an important effect on the development of this type of propulsion device. The diesel engine is essentially a constant torque prime mover. Maximum power cannot be obtained at rotational speeds other than that for which the engine is designed. Thus the speed-power relationships of the diesel and the screw propeller can only be matched efficiently at the design speed. One solution to this problem is the use of a diesel-electric propulsion plant; another is the employment of the controllable-pitch propeller.

The *Poseidon*, a diesel driven tanker, was fitted with a controllable-pitch propeller in 1915 but the absence of succeeding installations indicates that sufficient reliability was yet to be achieved. It was the blade control mechanism in the Kaplan water turbine in the 1920's which demonstrated the needed reliability to give impetus to the adoption of the controllable-pitch propeller by the marine industry.

The Swiss, sparked by their success with the Kaplan turbine, were the first to make extensive use of controllable-pitch propellers in numerous diesel-driven coastal transports, ferries, and tugs. These ships employed the Escher Wyss mechanism patented in 1933 in which a control rod for blade actuation was run through the shaft center in a manner similar to that originally patented by Hays.

In Sweden the controllable-reversible-pitch propeller provided the solution to a pressing problem. The diesel engines used in small fishing vessels were of a two-cycle design and burned a low grade of fuel. Because of this they were difficult to start, to reverse, and to change in speed. The Kamewa propeller provided the answer. It had a blade-actuating hydraulic servomotor and pressure-oil control valve located inside the hub with a tubular rod running through the shaft which transmitted the pressure oil and operated the control valve.

The Netherlands followed suit with the Schelde propeller. This device has a rod-controlled hydraulic servomotor and is unique in that the two pairs of blades are longitudinally separated thus permitting the hub to be no larger in diameter than that of a fixed-blade propeller.

The Germans installed a controllable-pitch propeller on the center shaft of the triple-screw cruiser *Leipzig*. The purpose of the mechanism, patented in 1925 by Dr. Mades, was to provide efficient cruising. The center shaft was diesel-driven with about 12,000 shaft horsepower whereas the two outboard shafts were turbine-driven with about 30,000 horsepower each. The installation was unsuccessful and the center wheel was replaced with a fixed-blade propeller.

The United States was much slower in taking advantage of controllable-pitch propeller developments. In 1940 the Navy fitted a mechanism to a 250 horsepower diesel tug which immediately went into foreign service, thus preventing tests. Because of the exigencies of wartime, controllable-pitch propeller installations in the 28,000 horsepower destroyer USS *Dahlgren* were never completely evaluated.

During World War II, however, extensive use was made of a simplified version of a controllable-pitch propeller by the U.S. Navy. This device was developed by the General Motors Corporation and was used in conjunction with the installation of one of their smaller diesel engines in some 1200 submarine chasers and infantry landing craft. The base of each of the three propeller blades was a truncated cone in which were cut slots to form gear teeth. The blades were rotated by fore and aft movement of a triangular rack. These propellers were extremely successful and required a minimum of maintenance. However their basic simplicity limited their versatility; it was necessary to cut the shaft speed down considerably in order to change pitch and frequent greasing was required to keep down gear wear.

In 1945 the U.S. Maritime Commission was planning the conversion of a Liberty Ship to gas turbine propulsion. Anticipating the need for a controllable-pitch propeller for this new power plant, it was decided to obtain some experience with an experimental controllable-pitch installation. The CI-M-AV1 cargo ship, M.V. *Single Hitch*, was selected and a propeller developed by the S. Morgan Smith Company was installed.

Single Hitch was a 338-foot ship powered by a 1600 horsepower, 180 rpm Nordberg diesel with direct drive. The controllable-pitch propeller mechanism was hydraulically operated, that is, the control rod running through the center of the shaft to the propeller hub was driven fore and aft by a hydraulic piston. This required a pressure distribution box to be mounted on the shaft. Some minor problems were encountered with cooling water getting into the hydraulic oil but in general the installation was eminently successful. It led to the ultimate installation in the gas turbine-driven Liberty Ship, *John Sargeant*.

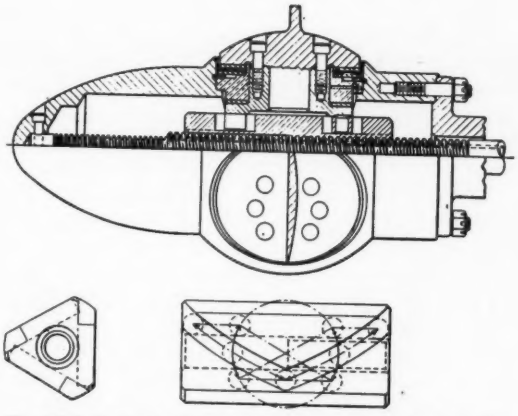
In 1946 a similar installation was made in the Navy 100-foot tug YTB 502. Extensive trials were carried out on this ship both free-running and with a tow. The results of these trials, compared with those on another tug of the same class with a fixed-pitch propeller, demonstrated the overwhelming superiority of the controllable-pitch propeller for towing service.

In 1950 the submarine USS *Grenadier* was fitted with controllable-pitch propellers. Difficulty was found with seals and with the pitch indicating mechanism which forced the replacement of the wheels with fixed-pitch propellers. But this installation did show that controllable-pitch propellers have many

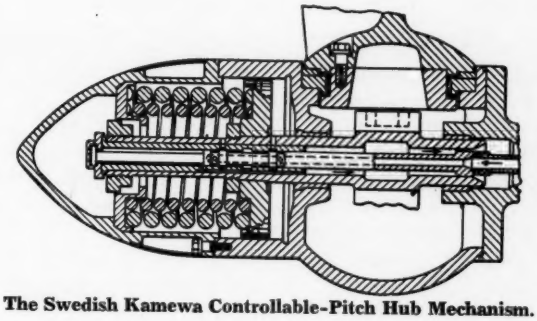
advantages for submarine use if the mechanical reliability can be improved to the point where no problems will be encountered in submerged operation.

There are still several variations of pitch-control mechanisms which are being suggested or which are being installed in operating ships. One type designed by the Manganese Bronze Company in England employs a gear and worm-wheel arrangement to rotate the blades. Another designed by G. Wislicenus for the Worthington Pump Company has prestressed cables wrapped around a drum at the base of each blade. Another mechanical type is the Nichols controllable-pitch hub mechanism which uses a threaded control rod which drives blade-connected crank pins through a curved groove to alter pitch.

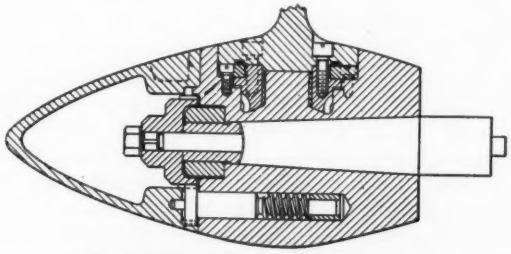
Several of these recent types of blade control mechanisms are shown in Figure 2.



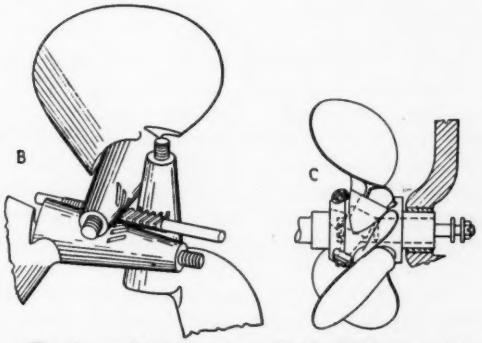
The Nichols Controllable-Pitch Hub Mechanism (1948).



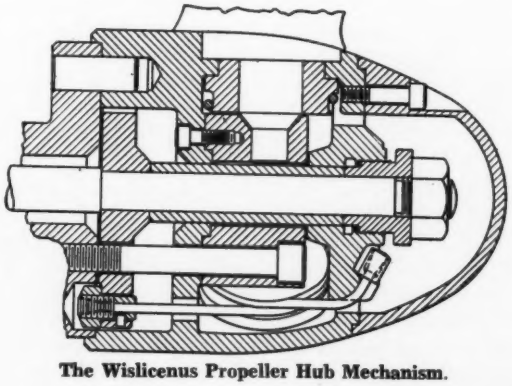
The Swedish Kamewa Controllable-Pitch Hub Mechanism.



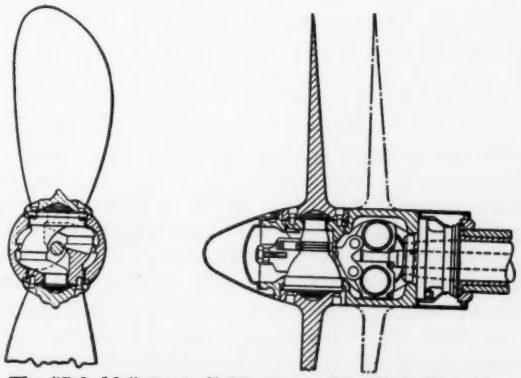
Controllable-Pitch Hub Mechanism
Designed by Manganese Bronze Company, England (1947)



The General Motors Controllable-Pitch Propeller.



The Wislicenus Propeller Hub Mechanism.



The "Schelde" Controllable-Reversible Pitch Propeller.

Figure 2. Modern Propeller Pitch Control Mechanisms.

The controllable-reversible-pitch propeller has proven to be an excellent special purpose propulsion device in those situations which call for its particular features. For several years now it has been going through an evolution of improvement in efficiency and reliability. As yet there is still some question as to its reliability for higher speed and power installations but it is obvious that in the near future it will have completely attained adult stature in the family of marine propulsion devices.

CONTRA-ROTATING PROPELLERS

Some of the earliest screw propeller installations employed a pair of propellers mounted on the same axis rotating in opposite directions. This was found primarily in the bladed-wheel types of screws, but the underwater-windmill devices also occasionally appeared in this form. The longer axial length of the Archimedian screw obviously did not lend itself to such an arrangement.

It is of interest to speculate why some of the earlier inventors such as John Ericsson attempted to use this principle when the mechanical difficulties which they must have encountered are so obvious. Ericsson claimed that contra-rotation gave an increased efficiency, yet in his twin screw designs he did not bother to take advantage of the efficiency he might have gained.

Nor does it seem probable that the unbalanced torque reaction of a single screw could have engendered any problems in heeling ships of the size on which most of these devices were installed. This then seems to lead to the conclusion that the real reason in back of the early adoption of contra-rotating propellers must have been the problems which cropped up in the yawing of the earlier ships when propelled by a screw.

This "walking" of the stern—to the right with a right-hand propeller and to the left with a left-hand propeller—might well have been a source of criticism of this form of ship propulsion. With the very low speeds at which they operated, often within restricted channels and with inadequate rudders, uncontrollable maneuvers could have been a very frequent occurrence. In fact, one of the basic objections to Ericsson's first craft by the British Admiralty was that steering would be impossible with the propulsion device at the stern.

Gradually these objections must have been overcome since the use of contra-rotation died out with the increased use of the screw propeller. Yet the principle certainly did not die. In 1888 Professor A. G. Greenhill, in a treatise on screw propeller theory, analyzed propellers operating on the same axis turning in opposite directions. And in 1892 a Swiss passenger boat was equipped with wheels of this design.

The first real experimental proof that increased propulsive efficiency could be obtained with contra-rotating propellers resulted from a series of tests by G. Rota in the first decade of the twentieth century. Working with a 46-foot boat at Castellammare di Stabia in Italy he proved conclusively that a gain in efficiency could be derived from this form of propulsion.

It was the military torpedo, however, which gave the major impetus to the development of contra-rotating screws for marine propulsion. The torpedo is a somewhat different type of waterborne vehicle than the surface ship or even the submarine. It is an extremely interesting vehicle in that its inherent symmetry can be used to advantage in producing an ideal hydrodynamic form and a wide variety of special types of propulsion systems are applicable to it.

Robert Whitehead, in 1864, began experiments which led to the development of the first modern type of self-propelled torpedo. Whitehead, who was superintendent of ironworks at Fiume, Austria, developed a torpedo by 1870 which had many of the characteristics found in the torpedoes of World War II. His weapon could be adjusted to run at depths between five and fifteen feet below the surface at speeds of fifteen to twenty knots. It could run a straight course and could be adjusted to stop at any time within its range and either float or sink at that point. Its range was 300 to 1000 yards and it could carry 33 pounds of explosive. Powered by a 40 horsepower, three cylinder, Brotherhood engine it proved to be a formidable weapon in its time.

Torpedoes evolved through progressive stages of development to those used effectively by submarines of the U.S. Navy in destroying the naval forces and merchant fleet of Japan in World War II. The two basic types of weapons used during that conflict were the steam torpedo and the electric torpedo.

The steam torpedo consisted of four major sections as show in Figure 3. The forward section was the warhead containing from 400 to 800 pounds of high explosive. Just aft of the warhead was the airflask section which occupied about one-third of the length of the torpedo. It contained an airflask of compressed air under high pressure, water tanks, fuel tanks, and control valves. The afterbody section contained the torpedo engine room. In it were the combustion flask, or boiler, the main drive turbines, and the reduction gears. The gears drove two concentric, contra-rotating shafts which drove the propellers. The tail section contained the propellers, exhaust valves, and the mechanism which controlled the vertical and horizontal rudders.

These torpedoes averaged 21 inches in diameter, 21 feet in length, and displaced about 3000 pounds. They were used by surface vessels, such as destroyers and patrol torpedo boats, and by aircraft, as well as by submarines. They had ranges from 4000 to 10,000 yards and attained speeds from 27 to 45 knots. They were primarily shallow running devices being designed to explode under the keel of the largest surface vessels operating at that time.

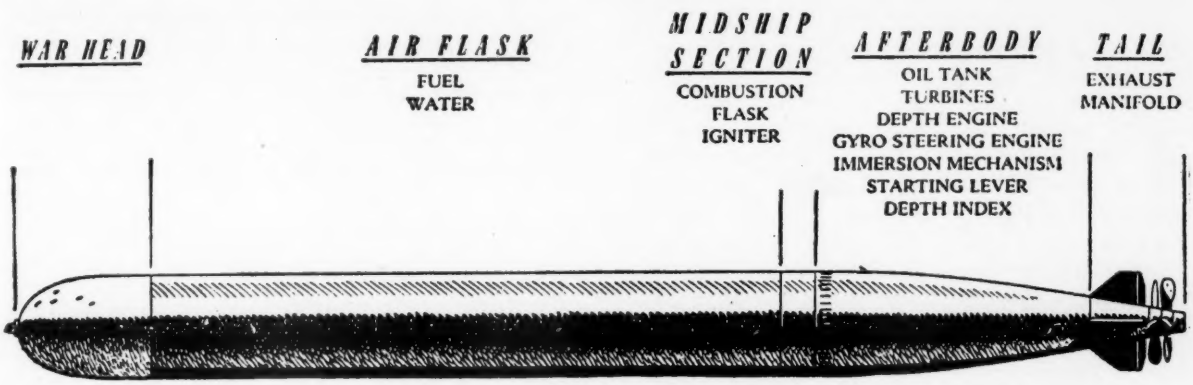


Figure 3. The World War II Steam Torpedo.

The electric torpedo was similar in general design to the steam torpedo. The air flask was replaced by storage batteries and the combustion flask and turbines by an electric motor. A small air flask located in the afterbody provided motive power for the operation of depth and steering controls. These torpedoes were used only by submarines because their construction was such that they could not withstand launching from surface vessels or aircraft.

The directional control system of these weapons utilized a gyroscope for primary guidance. Just prior to launching the axis of the gyroscope was set relative to the torpedo by a gyro-setting regulator. The vertical rudders were then actuated by an air system to maintain the torpedo on a course such that the gyro axis was always parallel to the torpedo axis. Depth control was maintained by the air-actuated horizontal rudders or diving planes. The control system consisted of a combination of a pendulum and a diaphragm mounted on the skin of the torpedo. The pendulum provided sensing of the angular inclination of the torpedo and the diaphragm indicated pressure, which is a function of depth. Prior to launching, the torpedo was set for a given depth of run which it then maintained from launching to impact.

Contra-rotating propellers were used in torpedoes for two primary reasons. First and foremost, the balanced torque reaction was essential to prevent rolling since the transverse stability of the torpedo is limited to that which is derived from the vertical and horizontal tail fins. A second reason for the contra-propellers is to permit a relatively high power to be transmitted by a small diameter wheel. When launched through tubes it is, of course, necessary that the propeller diameter be less than that of the torpedo body.

The Aerojet *Mini-Sub*, a small two-man submarine, is equipped with contra-rotating aircraft-type propellers for which an open water efficiency of 85 percent is claimed. For high speed, lightly loaded blades this sort of efficiency is possible. On larger single-screw submarines such as the USS *Albacore* (AGSS 569) it has not yet been necessary to go to contra-rotating screws. Yet if the tremendous torques which may be obtained in the future with nuclear power are applied in single-screw submarine installations, it may eventually be necessary to use propellers of this type.

Even in surface ships with increased power and a limitation on propeller diameter it may eventually be necessary to employ contra-rotating propellers to absorb the power within the available dimensions. But as of today this type of propulsion is limited in its application to specific types of waterborne vehicles.

THE KORT NOZZLE

The screw propeller is inefficient when operating at high slip. This condition exists when a tug is pulling a very heavy tow; under this condition the speed of advance is low but the propeller is rotating at fairly high speed. To obtain propeller efficiency at high slips it is desirable to increase the velocity of flow of water through the propeller to a value higher than the speed of advance of the ship. A device to accomplish this purpose was invented by Ludwig Kort in 1933 and patented in 1936.

As shown in Figure 4, the Kort Nozzle consists of a contracting nozzle, rigidly fixed to the ship, in which the propeller is mounted. The cross-section area of the nozzle is large at the inlet and is rapidly reduced to the propeller disc area at the propeller position. The velocity of the water entering the nozzle is correspondingly increased. Thus the propeller can operate at a lower and more efficient slip condition.

Two 325 horsepower diesel harbor tugs, the *Jane* and the *Marion*, were built with Kort Nozzles in 1939 by the Pusey and Jones Corporation for the Curtis Bay Towing Company. Their performance was rated outstanding by the operators and they

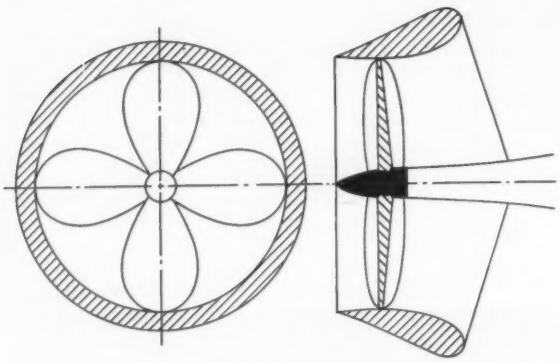


Figure 4—Sketch of the Kort Nozzle.

were said to compete on an equal basis with similar tugs of 500 horsepower. The first river towboat installation in the United States was made in a conversion of the *Neville* in 1939. This was followed by the *Wm. Penn* in 1940, the *Victory* in 1940, and the *Peace* in 1941. Since that time the Kort Nozzle has become a much relied upon propulsion device on the inland rivers of the United States.

In 1941 the United States Maritime Commission decided to use Kort Nozzles on the V4-M-A1 class of ocean-going tugs. These big tugs were 195 feet in length and were driven by two 1100 horsepower diesel engines geared to a single shaft. Extensive model tests were conducted on this design some of the results of which are shown in Figure 5.

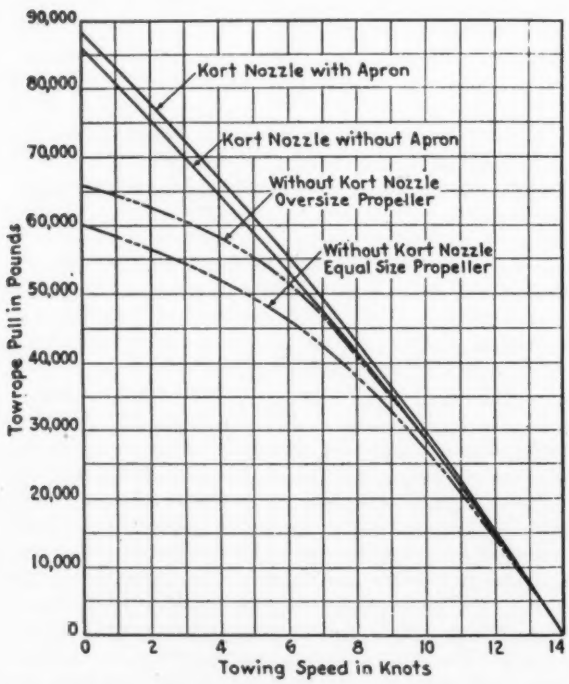
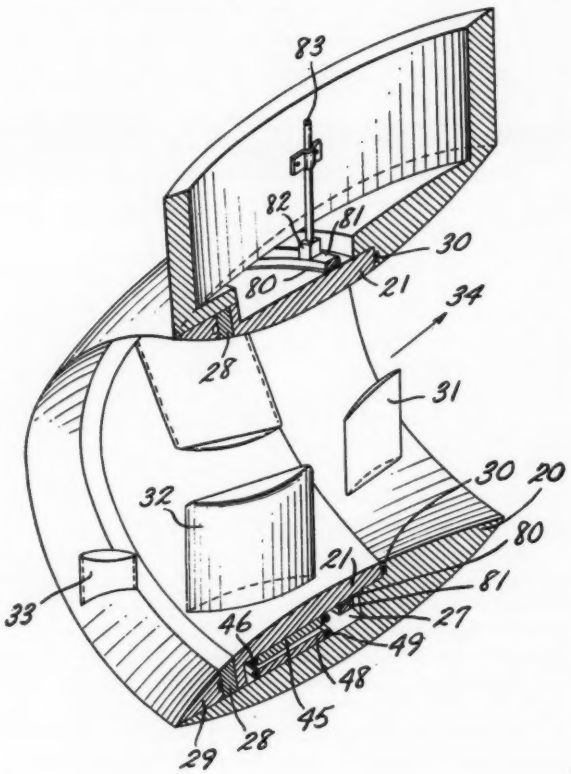


Figure 5. Model Test Results on the V4-M-A1 Seagoing Tug.

Due to wartime exigencies complete full-scale trials were not performed on these ships. But as an indication of their towing power the author personally witnessed the parting of a dynamometer on a dead pull bollard test in Milwaukee. The rated capacity of this dynamometer was 100,000 pounds!

Some variations of the basic Kort Nozzle have



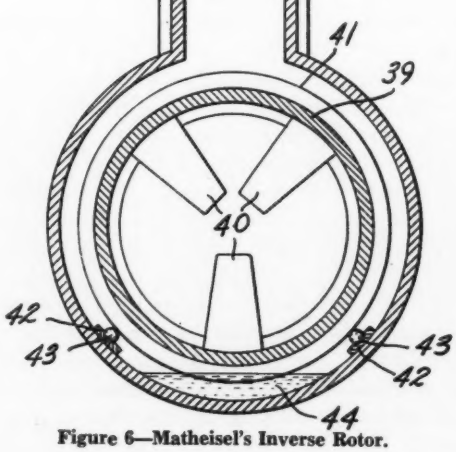


Figure 6—Matheisel's Inverse Rotor.

been proposed. One interesting inversion was patented by Rudolph Matheisel of Northfield, New Hampshire in 1950. His invention is shown in Figure 6. It consists of a nozzle in which the propeller blades are carried in a ring which rotates in bearings in the nozzle structure. Fixed vanes are installed fore and aft of the rotating blades to obtain better flow conditions.

The primary advantage of this device is that the propeller shaft, shaft struts, and propeller hub are eliminated, thus providing undisturbed flow to the blades. Whether these advantages will be offset by mechanical friction losses encountered in driving the large rotor and the obvious difficulties of sealing off the bearings from the corrosive effects of salt water can only be determined by experience with a full scale unit.

Another modification which has actually been tried in practice is the steering Kort Nozzle. This involves rotating the nozzle in the same manner as a rudder would be turned. The directional jet stream emanating from the nozzle can thus effect a powerful turning force on the ship. Again some mechanical problems have been found, but in all probability this combination of high thrust at low speed and controlled direction of thrust will eventually gain wide recognition.

The fixed Kort Nozzle has proven itself in one of the most exacting services in the world—inland river towboats. The Dravo Corporation of Pittsburgh, Pennsylvania, has been the prime developer of this propulsive device to its present position of eminence in towboat service. One of their installations is shown in Figure 7.

The Kort Nozzle as a solution to the low speed towing problem is a notable example of the great advantages which can be gained in designing special devices for specific marine propulsion requirements.

Figure 7. Kort Nozzle on an Inland River Towboat.

STEERING SCREWS

The idea of combining the thrust-producing device on a ship with means for steering the ship has long been a desire of marine inventors. If directionality can be given to the propeller jet, a much greater turning force can be applied to the ship than when a rudder is inserted in the propeller race.

One of the first references to using the screw propeller in this fashion was a very unique idea proposed by Bennett Woodcroft in his 1851 patent for a controllable-pitch propeller. One blade control arrangement which he devised permitted the blades of the propeller to twist on their axis independently in such a manner that each blade would move edgeways through the water during one part of a revolution and sideways during the remaining part of the revolution. By proper orientation of the control mechanism it was possible to obtain thrust in a direction perpendicular to the longitudinal axis of the ship thus creating a turning moment in the desired direction.

In 1862 William Joseph Curtis patented the steering screw shown in Figure 8. The propeller is mounted on the tailshaft through a universal joint and is carried on a bearing which is affixed to the rudder. When the rudder is turned the propeller axis is also turned, thus producing thrust in the desired direction.

S. W. Barnaby in his book on marine propellers in 1900 referred to a similar design as the patent of Mr. F. H. White. He pointed out that an additional ad-

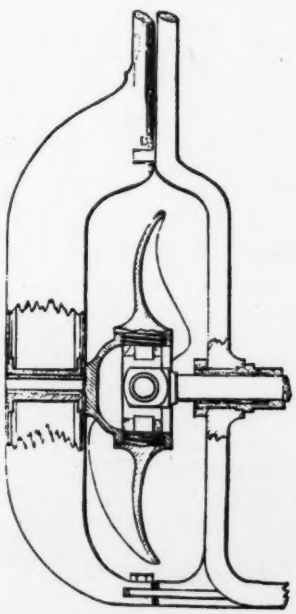


Figure 8. Curtis' Steering Screw.

vantage of this type of steering screw was the fact that once a turn had been initiated the forces developed on the propeller blades would be such as to hold the propeller-rudder combination in the turned position, thus requiring little additional effort to maintain the ship in the maneuver.

Another form of steering screw of a related type was suggested by Professor Victor Lutschaunig of the Imperial and Royal Academy of Trieste in 1874. This consisted of a small steering screw mounted at the after end of the rudder and driven by a shaft through the rudder which in turn was connected to the after end of the main propeller shaft through a universal joint.

In 1879 a steering screw was installed in the U.S. torpedoboat *Alarm* after removal of the Fowler Steering Propeller which will be discussed in a later section. This screw was devised by a Colonel Mallory. It was driven through a vertical shaft and bevel gear drive and was mounted under the stern of the ship. The supporting strut which contained the vertical shaft was free to rotate thus giving both propulsive and steering action to the screw. This screw could be rotated through a full 360°, thus providing for backing down as well as steering. Trials conducted in 1880 and 1881 found the device to be very successful.

In 1911 a form of steering screw was proposed by Macklind and Stroop for use in propelling and steering Mississippi River towboats. It was intended that the screw configurations should be similar to that of Colonel Mallory's with the engines mounted on deck both at bow and stern.

This proposal was actually put into use during World War II when diesel engine-driven pivoting screws were used extensively for barge and floating crane propulsion. These units, built by Murray & Tregurtha, delivered up to 300 horsepower, were relatively portable, and could be shifted from one barge to another. The engine itself was stationary but the vertical shaft driving the propeller permitted the propeller to be rotated through 360° in the horizontal plane. In addition, the vertical shaft bearings were pivoted at deck level so that the entire propeller assembly could be swung out of the water when not in use. One of these units is shown in Figure 9.

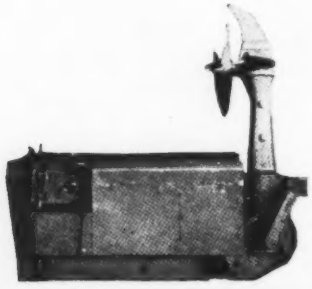


Figure 9. The Murray and Tregurtha Steering Screw Assembly with Propeller and Vertical Shaft in Stowed Position.

The outstanding modern example of the steering screw is the simple outboard motor used to propel so many sports and pleasure craft today. In this device the engine, vertical drive shaft, and propeller all can be turned together to give thrust in any desired direction. Figure 10 is a typical illustration.

Most of the earlier types of steering screws were plagued by mechanical and leakage problems which unfortunately resulted in damage and corrosion of the underwater mechanisms and required drydocking for repairs. It is only in recent year that a reliable means of providing directional thrust through a completely submerged mechanism has been developed.

This development came about from the application of a submersible well-pump motor to the steering of ships. In Germany, Pleuger & Co. developed a submersible A.C. electric motor which has been used for ship steering in the so-called Active Rudder. A small nacelle containing the motor is fitted in the rudder with a screw propeller mounted on the after end, as shown in Figure 11. The rudder is turned with the usual steering engine and the thrust of the propeller is delivered to the rudder stock at an angle

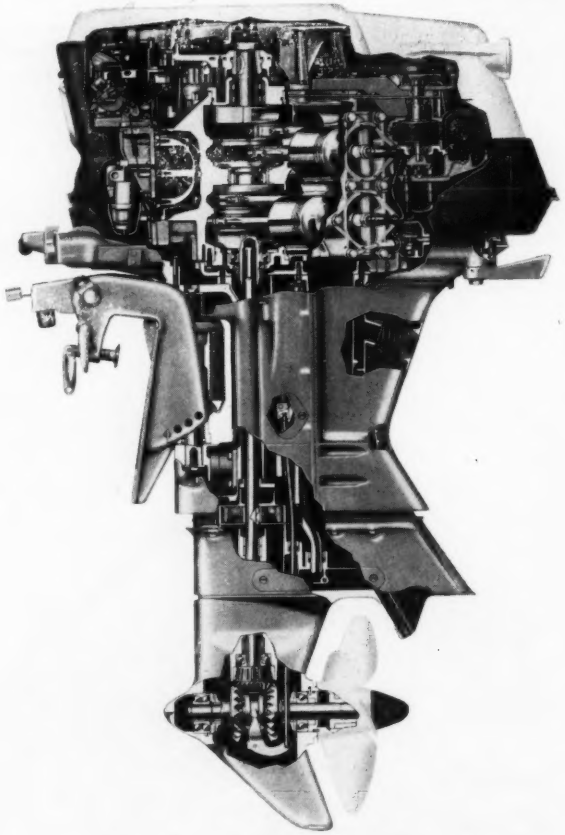


Figure 10. The Modern Outboard Motor.

Figure 11. The Pleuger Active Rudder with the Auxiliary Propeller Mounted in a Kort Nozzle.

to the ship centerline which is identical to the rudder angle.

This device became available in the late 1940's and has been installed in many ships such as tugs, trawlers, and minesweepers which must have good maneuverability when towing at low speed. It has also been suggested that the submersible motor-propeller combination be installed in the bow of oceanographic vessels which must hover for long periods when soundings are made. This form of bow traction installation would aid in holding the ship steady against wind and current.

Main propulsion steering screws do not appear to be entirely practical for large ships. They are, however, extremely well developed and reliable devices for propelling and controlling small craft. In addition, as auxiliary devices on larger ships which require good control and maneuverability they are a highly advantageous special purpose propulsion device.

THE VERTICAL AXIS PROPELLER

One of the most unique and interesting propulsion devices which supplies a controllable, directional thrust is the vertical axis propeller. The term vertical axis propeller includes that wide variety of propeller types which have been called horizontal paddle-wheels, rotating blade propellers, cycloidal propellers, and other descriptive cognomens. This term refers basically to those propellers having a vertical axis of rotation with a series of vertical blades displaced in a circle around the rotational axis to which are also imparted some form of rotation on their own axes.

The earliest example of a vertical axis propeller design was the horizontal watermill proposed by Robert Hooke in 1681 which has been described in a previous article. It had the basic characteristics of some modern-day vertical axis propellers with the exception that it was designed to extract power from the water rather than to apply power to it. A similar device was tried for ship propulsion by DuQuet at Marseilles in 1693.

One of the first references to such a propeller in a moderately successful shipboard installation was a patent applied for by Lt. W. W. Hunter in 1842. Hunter's propeller apparently consisted of a drum, with its axis vertical, around the periphery of which were placed a number of hinged paddles. The hinges were so fitted that when the paddles moved forward they lay against the surface of the drum; when the paddles moved aft they swung out against stops to provide a propulsive thrust. Model tests in the C&O Canal in Washington were so successful that the Navy undertook construction of a ship, the *Union*, for the specific purpose of testing this invention. The ship was 184.5 feet in length with a beam of 33.5 feet and depth of 16.75 feet, displacing 900 tons at a draft of 11 feet. The *Union*, in spite of several successive alterations, was difficult to maneuver and never attained a speed greater than six knots. The *Hunter* and the *Allegheny* were also constructed with this type of vertical axis propeller.

In about 1870 in Great Britain a Mr. Moody and a Mr. Fowler independently proposed another type of horizontal paddle-wheel which came to be known as the Fowler Steering Propeller. One of these propellers was installed in the U.S. torpedoboat *Alarm* in 1874. The unit consisted of a completely submerged horizontal paddle-wheel with feathering blades; it was mounted just abaft the sternpost. An adjustable eccentric on the vertical shaft controlled the feathering, and rotation of the eccentric would permit the delivery of thrust in any selected direction. The *Alarm* was said to be very maneuverable but very inefficient in forward propulsion. In 1879 the Fowler Steering Propeller was removed and replaced with the Mallory steering screw.

The first of the modern types of vertical axis propellers was developed by Professor Frederick K. Kirsten of the University of Washington with the support of Mr. William E. Boeing in 1921. The Kirsten-Boeing propeller was tested extensively in the University of Washington wind tunnels and in the Experimental Model Basin in Washington, D.C. Admiral D. W. Taylor said in a letter to Mr. Boeing

that the EMB tests demonstrated that this propeller could attain an efficiency decidedly higher than a screw propeller at small slips and lower at large slips. He believed that for ships with a wide flat stern higher efficiencies could be achieved with the Kirsten-Boeing propeller than with the conventional screw.

The basic mechanism of the Kirsten-Boeing propeller is almost identical with that of Robert Hooke's watermill and with many of the designs of feathering paddle-wheels. The principle of operation is shown in Figure 12. In this propeller the blade axes are

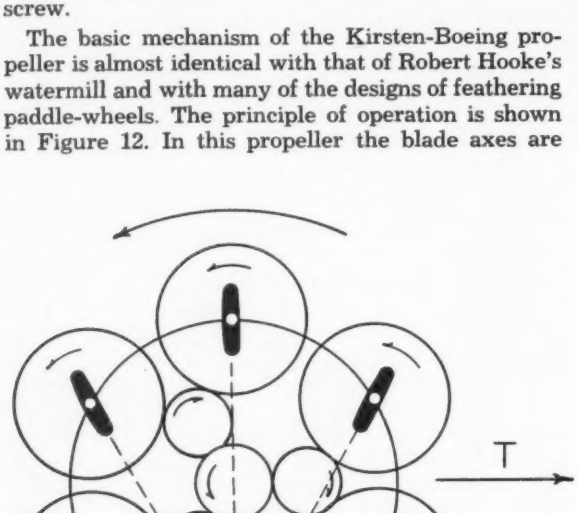


Figure 12. Diagrammatic of the Operation of the Kirsten-Boeing Propeller.

geared together in such a manner that each blade oscillates through a 180° arc for each complete revolution of the rotor plate. The arrows in the drawing indicate the directions of rotation and thrust. It can be seen that throughout more than half its travel each blade is delivering propulsive thrust and during the remainder of its travel it is coasting. The gearing arrangement is such that the phase angle between the blades and the rotor can be varied to provide thrust in any desired direction. The amount of thrust delivered can be controlled only by the speed of revolution of the rotor.

In 1926 an Austrian engineer, Ernst Schneider, developed another form of vertical axis propeller in conjunction with the German firm, J. M. Voith Co. The Voith-Schneider propeller is a much more sophisticated device than the Kirsten-Boeing propeller in that it provides pitch control. Blade angles are controlled through a series of linkages so arranged that not only the direction of thrust but the amount of thrust can be altered without changing the rotor speed. The two sketches of Figure 13 show the direction and relative amount of thrust for two different positions of the center control arm. The length of the directional arrow in each case indicates the thrust amplitude.

In all modern types of vertical axis propeller the blades are spade-shaped hydrofoils. They are mounted in a large circular plate which fits neatly into a broad flat area of the underwater body of the ship. The circular rotor plate is barely submerged and a

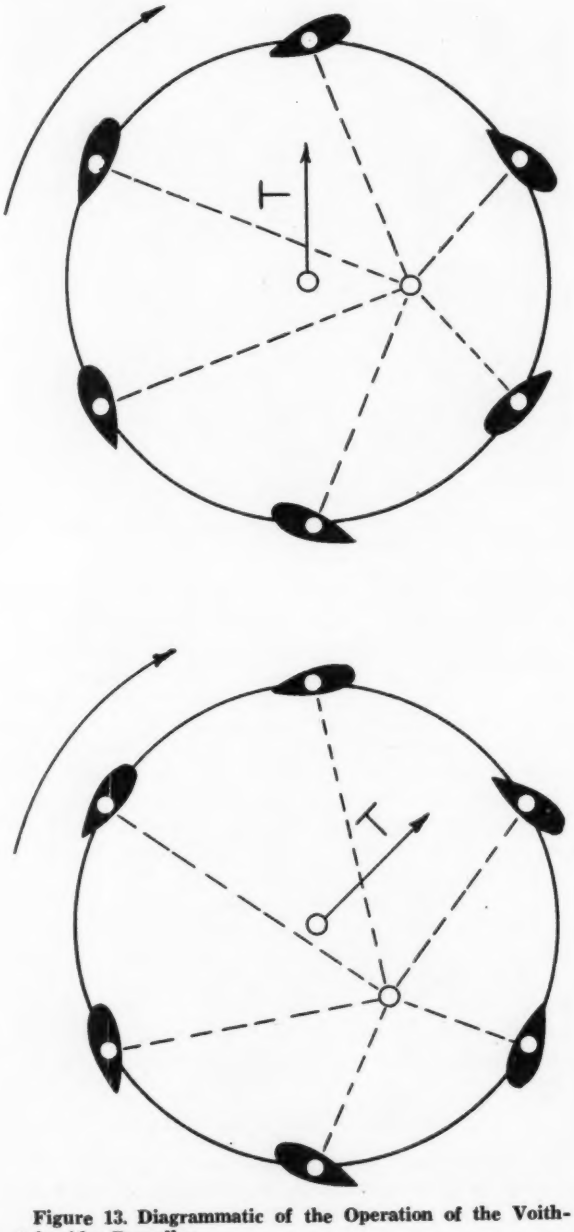


Figure 13. Diagrammatic of the Operation of the Voith-Schneider Propeller.

well is provided which extends above the waterline thus preventing water from leaking into the ship. Small vanes are frequently provided around the periphery of the rotor such that water flowing into the well is pumped out, thus reducing frictional resistance around the rotor casing.

The Voith-Schneider propeller became increasingly popular in Europe in the 1930's and 1940's for many special types of craft. The swift-flowing rivers of the continent were a natural element for this form of propulsion. During World War II the German Navy made extensive use of Voith-Schneider propellers in the R-Class minesweepers. These ships had twin propellers driven by 900 horsepower M.A.N. diesel engines. Maximum speed on these 135-foot ships was 18.5 knots and they proved to be very maneuverable and well adapted to the job of sweeping for mines.

The German Navy also installed Voith-Schneider propellers in a group of 350-ton floating cranes. The only one of these now in service was brought to the United States and is presently working out of the Long Beach Naval Shipyard. This, the largest floating crane in the world, is fitted with three vertical axis propellers, two aft and one forward. Each propeller is independently driven by a 700-horsepower electric motor. With a single operator at the controls this huge crane can be maneuvered with ease, moving forward, backward, sideways, or in a diagonal direction. It can be held easily against a wind or tide while working alongside a pier or a ship. The personnel aboard are enthusiastic in their descriptions of its performance under all sorts of adverse conditions.

After World War II a pair of Kirsten-Boeing propellers were fitted in a U. S. Navy landing ship (LSM 458). Although the hull of this ship was not specifically designed for vertical axis propellers, it did have many of the desired characteristics. Since these particular ships had a very low propulsive efficiency with screw propellers, on the order of 30%, it was not feasible to evaluate the relative efficiencies of the two means of propulsion.

Two Voith-Schneider propulsion units were brought to the United States in 1945 by the Army Transportation Corps. These were installed in a mineplanter specifically designed for vertical axis propulsion. This ship was later turned over to the Navy and designated *YMP-2*. It has performed its designed functions well in service.

Beginning in 1947 the U. S. Army Transportation Corps worked with the Pacific Car and Foundry Company to develop a simplified vertical axis propeller which had the flexibility of the Voith-Schneider unit but not its complexity. This was a controllable-pitch propeller but with a sinusoidal rather than a cycloidal motion of the blades. A diagram showing the action of the sinusoidal propeller is given in Figure 14. A comparative plot of the blade motion of the Kirsten propeller, two types of cycloidal motion, and sinusoidal motion is given in Figure 15.

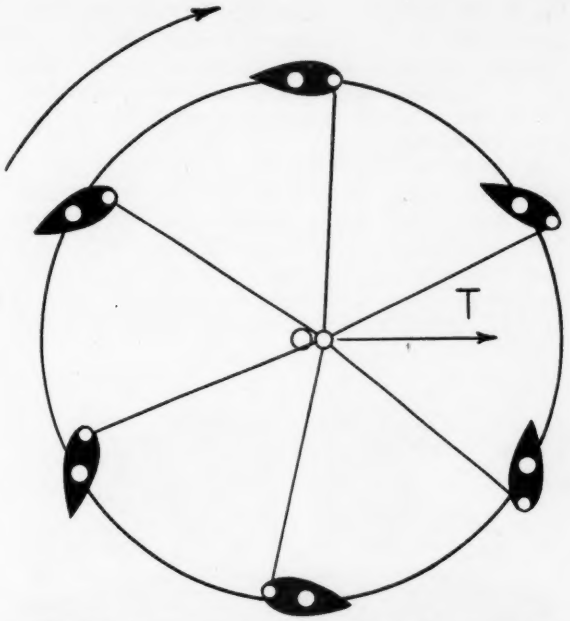


Figure 14. Diagrammatic of the Operation of the Sinusoidal Propeller.

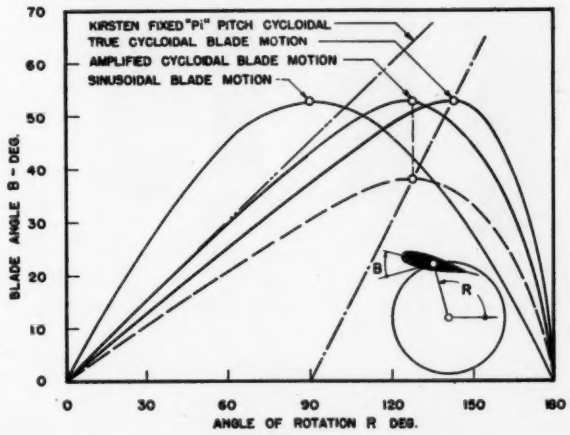


Figure 15. Comparative Blade Motions of Various Types of Vertical Axis Propellers.

The sinusoidal propeller was first installed in a small tug which performed amazing maneuvers with ease. A similar unit was built into the bow of the *Northampton*. This was an LST converted for service as a ferry. The bow propeller was provided for the difficult docking problems which had to be met by this ship.

The ability of the vertical axis propeller to withstand rugged commercial service was demonstrated in the U. S. Army Towboat *LTI-2194*. This ship was fitted with sinusoidal propellers and was operated

for the Army by the Mississippi Valley Barge Line for a period of two and one-half years. The towboat was in regular commercial service on the Ohio, Illinois, and Missouri Rivers, and was praised for her ability to handle large tows under difficult operating conditions.

Recently the Army Transportation Corps built a beach discharge lighter *Lt. Col. John P. D. Page*. The *Page* is 338 feet in length with a beam of 65 feet and displaces 2,549 tons at a mean draft of 10 feet. She is equipped with two 1,200 horsepower vertical axis propellers and has a designed speed of over 12 knots. Figure 16A is a photograph of a propeller similar to those installed in this ship, and Figure 16B is a sectional view of one of the *Page's* propellers.

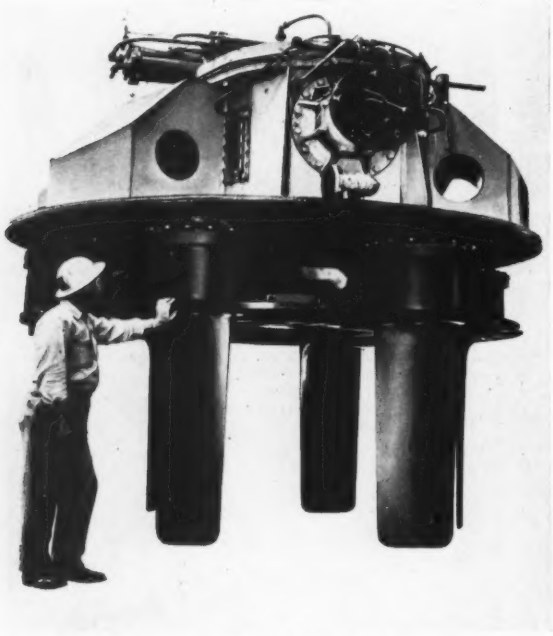


Figure 16A. A Typical Vertical Axis Propeller Assembly.

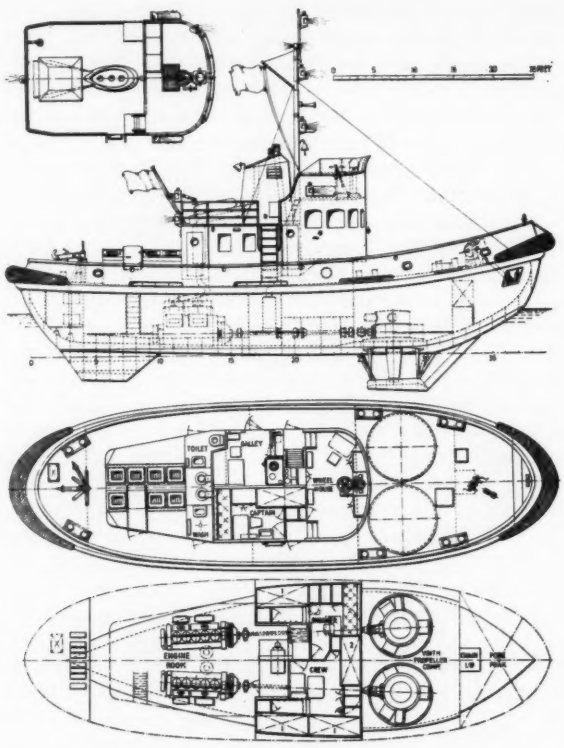


Figure 17. The Voith *Watertractor*.

Although the sinusoidal propeller now seems to be favored in the United States, the Voith-Schneider propeller is being used extensively abroad. One of the latest designs employing it is the Voith *Watertractor* shown in Figure 17. One of the most in-

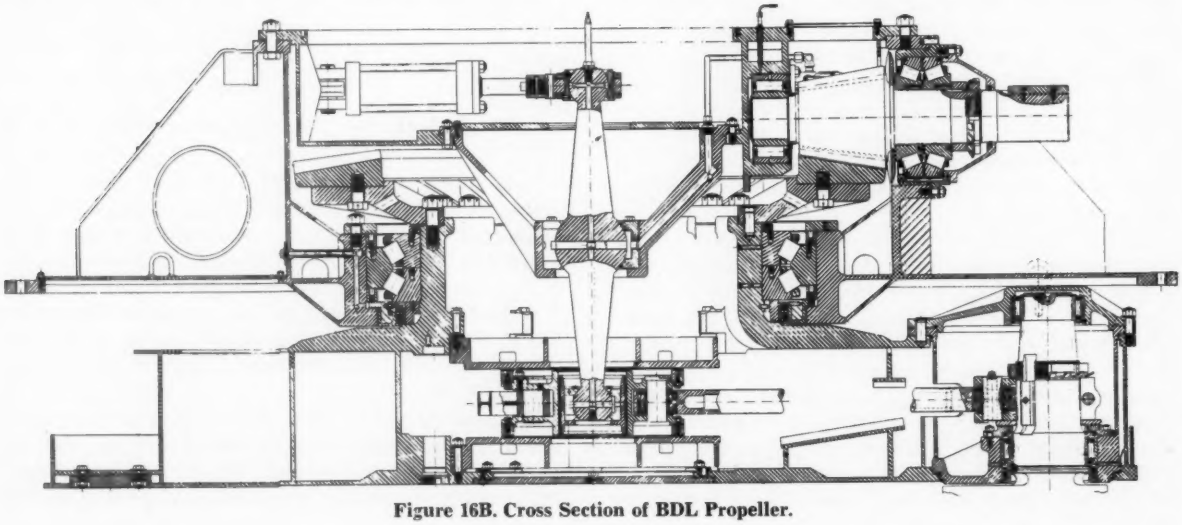


Figure 16B. Cross Section of BDL Propeller.

teresting features of the design is the forward location of the twin propelling units with the engines mounted aft. The propellers are protected from underwater damage by a skeg arrangement which is designed as a hydrofoil to produce an augmented thrust at high slips in a manner similar to the Kort Nozzle.

The machinery and propeller arrangement permits the towing hooks or bollards to be located at the stern rather than close to amidships, as is required for effective rudder action on a screw-propelled tug. The towline can thus always be directly in line with the propulsive thrust and the problem of heeling the ship under tow is avoided. The *Watertractor* is also designed to operate as a pushboat when going astern.

The vertical axis propeller is gradually finding its place in the marine propulsion field. It cannot compete with the screw propeller in ships designed for long ocean voyages but where a high degree of maneuverability is required the vertical axis propeller is a versatile and useful propulsion device.

EDITOR'S NOTE: *In Part II of this paper which will be published in the November 1959 issue of the* Journal, *the author presents:*

Air Screws.
Surface Propellers.
Tracked Vehicles.
Hydraulic Jets.

with appropriate conclusions and bibliography.

ACKNOWLEDGEMENT

Part of the literature search on which this article is based was done under contract DA-44-77-TC-409 with the U.S. Army Transportation Corps.

The largest tanker yet built in an American shipyard has recently completed an unusually extensive agenda of sea trials. The PRINCESS SOPHIE, designed by the Central Technical Department of Bethlehem Steel's Shipbuilding Division, and constructed at the Quincy yard, is the first American built tanker that cannot traverse the Panama Canal. The sea trials included standardization of SHP and RPM over the measured mile, ahead and astern steering, turning circle data, crash stops from ahead and astern, fuel consumption, and several others. Very complete instrumentation included strain gauges for rudder stock torque measurements and more than 400 accelerometers for vibration measurement and analysis. Having passed her trials with flying colors, the ship is now in the service of its owner, the World Brilliance Corporation of Monrovia, Liberia. The principal characteristics of the ship are:

Length, overall	859 ft.
Beam	115 ft.
Depth	60 ft.
Draft	44 ft.
DWT	71282 tons
Displacement	91350 tons
Cargo capacity	647,500 bbl.
SHP	23,000
Speed	16½ kts.

—from MARINE ENGINEERING/LOG, May, 1959

THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.
Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

"MECHANICAL ENGINEERING"

FUEL CELLS

ACKNOWLEDGEMENT

This article appeared in the March 1959 issue of "Mechanical Engineering."
The authors are Everett Gorin and Howard L. Recht, of the Research and Development Division, Consolidated Coal Company, Library, Pennsylvania.

RESEARCH on the fuel cell has been carried out sporadically for almost a hundred years, but there has been a decided awakening of interest in recent years. By definition, a fuel cell is a primary electrochemical device which effects the oxidation of a fuel with conversion of a substantial portion of the heat of combustion directly to electrical energy. A true fuel cell must operate continuously with a steady and constant output of electrical energy and with continuous supply of fuel to the negative electrode and of oxidant to the positive electrode. Only recently have fuel cells been devised which begin to meet this criterion of steady output.

Why is there such a widespread interest in the fuel cell? In a broad sense, the main attraction is the potentially higher efficiency that can be achieved in the conversion of natural fuels to electrical energy. It does not, in itself, introduce a new source of energy such as in the case of nuclear fission and fusion. Its main function would be to extend our resources of fossil fuels.

A number of different types of fuel cells have been under development. All cells for which any success has been claimed operate with gaseous fuels, and discussion will be limited to these. Ultimately, of course, the authors' company is interested in the use of solid fuels, particularly coal, which is by far our most abundant fossil fuel for generation of power. Prior gasification of coal can be used to produce fuel gas for use in the fuel cell. As will be discussed further, this operation can be conducted in integration with the fuel-cell process itself to produce a high potential efficiency for generation of power from coal as well as from other natural fuels.

There are really two basic types of fuel cells that have been under development. The low and medium-temperature cells operate broadly in the temperature range of room temperature to about 250°C. These cells are characterized by the fact that high output is only achieved when relatively pure hydrogen is used as the fuel and pure oxygen as the oxidant.

The most highly developed cell of this type operates at moderately elevated temperatures and at relatively high pressures of about 600 psi. This is the cell developed by F. T. Bacon [1] in England, whose use in this country is being developed by the Patterson Moos Division of the Universal Winding Company.

These hydrogen-oxygen cells have achieved considerable success in the course of their laboratory development. They are of interest for specialized military and possibly civilian applications. In their

present state of development, however, they cannot be regarded seriously as a major power source. This is because the cost of the fuel and of the oxidant is as great as the cost of power generated directly from natural fuels by more conventional methods. Even the apparent advantage of the fuel cell for generation of power at a high efficiency level tends to disappear with this kind of cell. This can be shown by reference to Table I. Here we see the over-all balance for a scheme where electric power is generated from methane by way of its prior conversion to hydrogen and its final combustion in a high-pressure Bacon type cell. It is seen that the over-all electrical efficiency, based on the methane feed, is somewhat smaller even than one obtains by more conventional power-generation methods.

TABLE I. *Energy balance in operation of hydrogen-oxygen cell at 600 psi 1 lb. mol, CH_4 as primary fuel*

Gross heating value, Btu		
Methane feed	383,000	
H_2 product at 100 psig.	233,000	
Electrical energy in Btu equivalents at		
Current density, amp per sq. ft.	9.3	93
Voltage	1.02	0.905
Produced in cell	160,800	142,500
Consumed in oxygen plant	21,500	21,500
Consumed for gas compression	14,400	14,400
Net electrical energy	124,900	106,600
Over-all electrical efficiency, in per cent	32.7	27.8

HIGH-TEMPERATURE CELLS

The other type of cell that has been under development in various laboratories in the world is the so-called high-temperature cell. This cell is characterized by the fact that the operating temperature is above 500°, principally in the range of 500° to 850°C; that operation is carried out at atmospheric pressure; that air can be used as the oxidant; and that ordinary fuel gases which can be generated directly from coal or other fossil fuels such as water-gas can be used. The most extensive work in this field has been carried out in Holland at the University of Amsterdam under Ketelaar.[2,3] Considerable success has been obtained in this work and cells have been devised which show steady operation at operating temperatures for periods of six months.

EXPERIMENTAL WORK

The authors' company has been working for several years under Signal Corps sponsorship on the development of a high-temperature fuel cell. The work paralleled fairly closely that performed at Amsterdam. The type of fuel cell that was used is shown in Figure 1. Any commercial development that arises would, in all likelihood, operate on a similar principle.

The fuel cell is composed of two flanges between which an electronically insulating but electrolytically conducting electrolyte matrix is disposed. This matrix is composed of a porous-magnesia refractory. It is impregnated with a molten carbonate mixture which serves as the electrolyte.

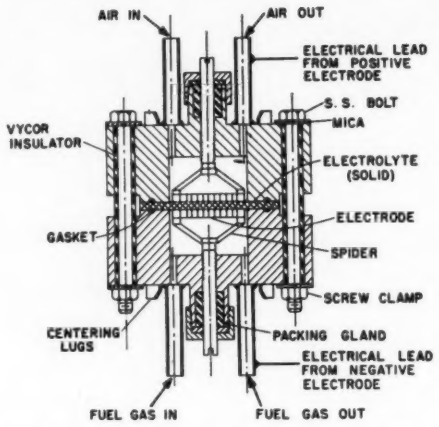


Figure 1. Experimental high-temperature fuel cell.

Two porous electrodes are disposed in the gas chambers on either side of the electrolyte matrix. Fuel gas is passed in and out of one of these chambers while air passes in and out through the other one. The air electrode is composed either of a porous sintered semi-conducting nickel oxide or of silver-wire gauze. Equally good results can be obtained with either. The fuel-gas electrode can be porous sintered-nickel metal, although other materials, such as porous iron, can be used. Figure 1 illustrates one of the authors' earlier fuel-cell models. Work is now being conducted with pressurized double-porosity-type electrodes for which much better performance is anticipated.

Good operating characteristics have been attained with these cells using carbon-monoxide carbon-dioxide mixtures as the fuel gas with an iron-activated fuel electrode. Broers and Ketelaar have obtained very good performance with a similar system where the iron activator is backed up with a silver-gauze electrode. The porous-nickel, single-porosity electrode gives fair performance with CO-CO_2 mixtures. This is illustrated in Figure 2 where the cell voltage under steady operating conditions is shown as a function of the carbon-monoxide carbon-dioxide ratio and the current density and the temperature.

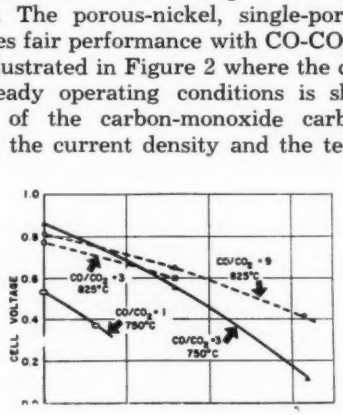


Figure 2. Cell performance data with CO-CO_2 fuel gas.

The theoretical open-circuit voltage for these mixtures is of the order of one volt.

Nickel, however, operates very well as a fuel electrode when hydrogen is present. Figure 3 shows similar data on cell operating characteristics at 750°C for a hydrogen-steam mixture as a fuel gas. The open-circuit voltage of the cell changes with current density due to change of gas composition as a result of the cell reaction. This change was calculated by means of the Nernst equation and the corrected voltage is shown as the upper curve. The *IR* drop in the cell is the difference in voltage between these two curves. It is found that the *IR* drop is equal to the resistance measured with an a-c bridge. We therefore conclude that the cell operates without polarization with a hydrogen fuel gas. No polarization was observed at the air electrode at the current densities up to 125 milliamperes per sq. cm., using either lithiated nickel oxide or silver gauze.

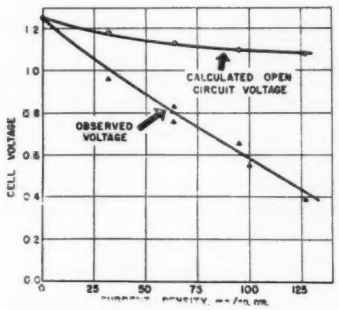


Figure 3. Cell performance data with H_2-H_2O fuel gas at 750°C

POTENTIAL APPLICATION

What is the potential of the high-temperature fuel-cell system as a primary energy source? Several factors will determine the over-all economics of such an operation. First, the fuel cost which is a reflection of the thermal efficiency of the cell. Second, the investment and operating costs must be considered. These latter two costs are very much a function of the cost of the individual fuel-cell elements and of their life. It is difficult, at the present time, to get a realistic estimate of the cost of the elements in the fuel cell since many of the materials are either not manufactured at all or made on a very small scale. Cell life, it would appear from the authors' work and that of Ketelaar,[2,3] can be of the order of at least six months. However, the ultimate life must be larger for such a system to be practical. The cell output per unit of electrode area also will have a great bearing on the economics of the operation of the system since the cost of the individual electrode area is fairly well fixed.

The authors' work and that of Ketelaar [2,3] have shown that a current output of the order of 35 amp. per sq. ft. can be obtained at an operating voltage of 0.75, but a detailed theoretical analysis shows that

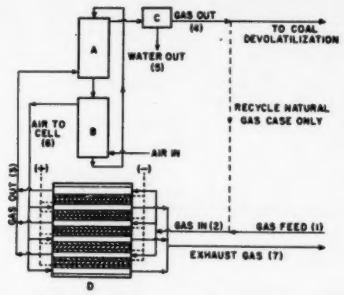


Figure 4. Integrated fuel-cell systems.

further cell development can yield a current output of 200 amp. per sq. ft. at the operating voltage of 0.75. Such a current output would, if the cell were sufficiently long-lived, approach that required for commercial operation.

The other important factor in the fuel cell is the over-all thermal efficiency for conversion of the original fossil fuel to electrical energy. An integrated system for effecting this conversion using either coal or natural gas as fuel is shown in Figure 4. The scheme shown is based on the premise, which has been demonstrated by prior work, that carbon dioxide addition to the air is necessary to achieve a high-output fuel cell. We see here a high-temperature cell composed of rectangular elements disposed in parallel through which the fuel gas is passed countercurrent to the air. The system shown at *A* and *B* is a circulating-carbon-dioxide-acceptor system which operates countercurrently and adiabatically to effect the transfer of CO_2 from the exhaust gases leaving the cell to the air entering the cell. The cells have re-forming catalysts disposed in the gas channel to convert methane into CO and hydrogen. The heat released during the cell operation is available to carry out this endothermic reaction. The gas leaving the CO_2 acceptor system is rich in hydrogen and may be either simply recirculated where natural gas is used as fuel or passed through a coal hydrogenation or hydrodevolatilization zone to produce the gas required for fuel-cell operation.

An over-all heat material balance has been made around the operation of such a system based on rather extensive knowledge of the coal hydrogenation-gasification [4] operation. This balance was made around a fuel cell operating at 0.75 volt. The efficiencies for three sources of fuel to the cell are shown in Table II. The first is gas produced by hydrodevolatilization of coal; the second is gas from complete coal hydrogenation; and the third is natural gas. It is seen that the efficiency attainable ranges up to 70 per cent for complete conversion of the coal. Another system which can be used for complete coal conversion which was not illustrated involves gasification of the coal with steam in indirect heat-exchange re-

TABLE II. *Over-all maximum electrical efficiency*

	H T COMBUSTION, BTU
A. *Coal devolatilization*	
100 lb. coal to devolatilization	1,438,000
4.8 lb. char. burned to supply endothermic heat of devolatilization	70,000
	1,508,000
58.1 lb. char. product from devolatilization	844,000
Net fuel consumed	664,000

$$\text{Efficiency} = \frac{100 \times \text{Btu equivalent of electrical energy at 0.75 volt}}{\text{Net fuel consumed}} = \frac{396{,}000}{664{,}000} = 59.7 \text{ per cent}$$

B. *Complete coal conversion*	
100 lb. coal	1,438,000
Btu equivalent of electrical energy generated at 0.75 volt	998,000

$$\text{Electrical efficiency } \frac{998{,}000}{1{,}438{,}000} = 69.5 \text{ per cent}$$

C. *Methane combustion*	
1 lb. mol. methane in	383,034
Btu equivalent of electrical energy at 0.75 volt	249,000

$$\text{Electrical efficiency } \frac{249{,}000}{383{,}034} = 65 \text{ per cent}$$

lationship with cell operation. Such a system shows a potential electrical efficiency as high as 75 per cent.

As already pointed out, nothing can be said as yet about the ultimate economics of the fuel cell. However, it is clear that the fuel cell is an extremely promising method for generation of power and that there is every indication that by further development work a cell could be developed with sufficient stability and high enough output for commercial use. It is possible to make a comparison of the fuel costs that can be achieved by use of a fuel cell operating at 70 per cent over-all thermal efficiency as compared with fuel costs involved in generation of nuclear power and by conventional steam plants based on coal. This is given in Table III.

The fuel costs for nuclear plants are extremely uncertain and one must take the best estimate from the many available. The first generation of nuclear power plants is expected to show a fuel cost in the neighborhood of 5 to 6 mills per kwh.[5,6] The second generation of nuclear plants is expected to show a much lower fuel cost which is generally not too well defined. The figures shown in Table III, of 1.7 to 2.0 mills per kwh,[5,7] are the lowest estimates known to the authors for such second-generation plants. Similarly, ultimate nuclear fuel cost is even more indefinite, but a value of 1 mill per kwhr has been arbitrarily assigned.

TABLE III. *Comparison of estimated fuel costs, nuclear and coal-based power plants*

	First generation 1960-1961	Second generation 1963-1965	Ultimate
Nuclear fuel cost, mills per kwhr	5.8	1.7 to 2.0	1.0
Competitive coal costs, cents per million Btu			
Steam plant heat rate, 8500 Btu per kwhr	68	20 to 24	12
Fuel cell heat rate, 4850 Btu per kwhr	120	35 to 41	21

It is seen that the fuel cell would permit coal to remain competitive with nuclear power on the basis of fuel cost over a much longer period than would be the case for a conventional steam plant. As a matter of fact, the figures indicate that the fuel cell could show a lower fuel cost than a nuclear plant at a location close to the coal mine for the indefinite future.

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NOTE: Two recent review articles on fuel cells are: F. T. Bacon and J. S. Forrest, "High-Pressure Hydrogen Fuel Cell," *Engineer,* vol. 202, July 20, 1956, pp. 93-94, from Fifth World Power Conference Paper No. 119K/4, Vienna, Austria, 1956; and E. K. Rideal, *Zeitschrift für Elektrochemie,* vol. 60, 1958.

ENSIGN MERVYN LEA RUDEE, U.S.N.

THE EFFECT OF IRRADIATION ON CREEP

THE AUTHOR

attended Stanford University as a member of the Regular NROTC. He graduated with a B.S. in Metallurgical Engineering in 1957. After completing some graduate training, he entered the Navy and served in the Engineering Department of the U.S.S. Navarro (APA 215) for seven months. He is currently attached to U.S.S. Kearsarge (CVS 33). He has had experience in the high temperature alloy development program at Stanford Research Institute at Menlo Park, Calif.

INTRODUCTION

Creep is defined as plastic deformation under an applied stress that is less than the value of the yield stress. Though many mechanisms have been proposed to explain creep phenomena, none has been entirely successful under all conditions. A somewhat arbitrary but useful classification of processes which can occur during creep is given by Schoeck (1):

1. Crystallographic slip or glide of the dislocations on the slip plane.
2. Subgrain formation or climb of dislocations.
3. Flow of grain boundaries.
4. Diffusion of vacancies or interstitials.

These four mechanisms contribute to the whole macroscopic deformation to varying degees; depending on temperature and stress. The last mechanism is only observable at high temperatures and low stress conditions and is negligible under most test and engineering conditions (2). The third mechanism on the list is also of a lesser magnitude. Parker and Washburn report that even at temperatures close to the melting point the amount of creep produced by grain boundary flow is less than ten percent of the total (3). Thus, it is clear that the majority of deformation in creep can be attributed to the first two mechanisms on the list.

The mechanisms of creep have been divided generally into low and high temperature phenomena. The rough dividing line is usually taken to be one half of the absolute melting point. Typical creep curves are shown in Figure 1. Here the classic three stages of creep can be seen in the higher temperature or stress example. The three stages are labeled transient (I), steady state (II), and accelerated (III). At lower temperatures the strain rate in the steady state

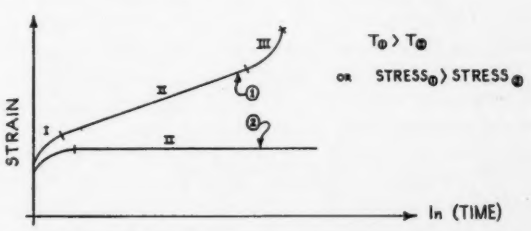

Figure 1. Typical Creep Curves at Constant Load.

stage is zero and the fracture is never reached. The first modification to this picture was the explanation of the third stage. It was found that this stage was always accompanied by necking and that tests run at constant stress, not constant load, eliminated this stage. The creep curves at constant stress appear as in Figure 2.

There have been two theories proposed to explain the reduction of creep rate that brings about the second stage. Mott and Nabarro proposed that the exhaustion of Frank-Read sources produced the rate reduction (4), while Orowan attributes the reduction to work hardening (5). Most recent work seems to favor the latter view. Parker proposes an integrated

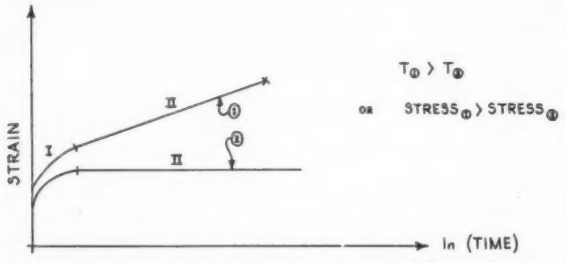

Figure 2. Typical Creep Curves at Constant Stress.

mechanism that is based on the equilibrium of two processes, dislocation locking and climb (3). He states that there is no distinction between the transient and steady state behavior and that all creep behavior follows a parabolic law. He also attributes the slowing of the creep rate to the locking of the dislocations. This process is opposed by climb, and the relative strengths of these processes determine the strain rate. This view has been substantiated by Dorn and Sherby who found a close correlation between the activation energies for creep and self diffusion; the latter being the rate controlling process for dislocation climb (6). At low temperatures the climb process is retarded and deformation cannot occur.

EFFECT OF RADIATION ON CREEP

Historically, the first reported findings concerning the effect of radiation on creep was the work of Andrade (7). He was studying the effect of surface properties on creep and used alpha emission from a polonium source as a method of altering the surface of cadmium single crystals. He found that the creep rate was increased significantly, but he gave no quantitative results. Later Makin performed some experiments similar to those of Andrade (8). Using lower temperatures and different flux and crystallographic orientation, he found no significant change in the creep rate. Despite the differences in experimental procedure he concluded that the increase found by Andrade could be attributed to geometrical or surface phenomena. Dienes concludes that since the alpha particles only penetrate 0.005 mm., the increase in creep rate was dependent on surface damage triggering dislocation glide (9). Work by Witzig showed no effect on the creep rate of copper irradiated by alpha particles (10). Jeppson, et. al., first found a decrease in the creep rate of aluminum of 30 percent to 60 percent with an alpha flux of 2.4×10^{13} alpha/cm^2/sec. Later with a flux of 1.2×10^{13} alpha/cm^2/sec. they found a decrease of 19 percent but considered this later work to be inconclusive (11). From the limited work done, few definite conclusions can be drawn about the effect of alpha radiation on creep. However, it does appear to be closely involved with the surface conditions and size of the sample. In practice the effect of alpha particles does not have the engineering implications that neutron irradiation has.

Despite its importance in the construction of reactors there has been very little work done on the effect of neutron irradiation on creep. Much of the paucity of data is produced by the difficulties incurred in in-pile testing. Some of the difficulties are best illustrated by the works of Jones, Munro and Hancock (12). In early work on the creep of commercially pure aluminum, they found that radiation damage to the strain gauges was more severe than the change in creep rate. To surmount this obstacle they devised a novel method for measuring strain. They inserted their specimens in venturi tubes and passed a known volume of air through the tube. The strain was measured by the change in pressure drop through the tube brought about by the reduction in cross-sectional area of the specimen. From this data the elongation was calculated by the use of Poisson's ratio. This method was used because tubes could be built that had adequate dimensional stability under irradiation and the sensing elements could be removed from the source of radiation. However, they found that the ambient temperatures in the reactor negated the comparison of their in-pile data with published figures. This problem was solved by the construction of a similar venturi tube creep device that was furnace heated and controlled to follow the temperature of the reactor. Two similar specimens were tested simultaneously and the results compared. Their findings for 99.8 percent pure aluminum with a flux of 1.3×10^{12} fast and 6.0×10^{12} thermal neutrons showed a significant increase in creep rate, but they would not give any quantitative results. Other workers in this field have encountered similar difficulties. Faris has summarized the work done in the United States on the effect of irradiation on creep and this is reported in Table I (13).

PROPOSED MECHANISMS FOR THE EFFECT OF RADIATION ON CREEP

Cotrell lists five possible methods by which radiation could affect the creep properties of metals (14).

TABLE I
The Effect of Neutron Irradiation on Creep

Material	Flux n/cm²/sec	Temp °C	Energy in Mev	Ratio $\frac{\text{in-pile}}{\text{out}}$	Stress kg/cm²
Al	8×10^{11}	350	>0.6	0.5	62.6
Ni	3×10^{11}	700	>0.5	little	141
	6×10^{12}	500	>0.5	none	?
Zr	3×10^{12}	260	>0.5	20	1265 and 2530
	3×10^{13}	260	>0.5	10	1090
Constantan	3×10^{13}	300	fast	no effect	1270
Inconel	5×10^{12}	705	>0.1	little change	420
Type 347 Stainless Steel	?	760	?	slight increase	?
	?	760	?	slight increase	?

These are:

1) The Nabarro effect, in which point defects created by radiation are absorbed preferentially on certain dislocations or on certain parts of the crystal boundary, thus changing the shape of the crystal in the direction of the applied stress (2). He shows that, with no stress gradients, creation of interstitial-vacancy pairs causes no deformation. However, for the case of a stress gradient, he derives the following equation for the strain rate:

$$\text{strain rate} = \frac{2a^2\mu}{kT} \text{ grad } (W_{1v}+W_{2v}+W_{1i}+W_{2i})$$

where

A = linear grain dimension
a = (atomic volume)$^{1/3}$
μ = loss of holes or ions through diffusion to the boundary
$= Aa^2\phi$ for small values of ϕ

$$= \left[a^3\phi\pi_v\pi_i/(n_v\pi_v+n_i\pi_i) \right]^{1/2}$$

ϕ = neutron flux
π = frequency of jumps by interstitials or vacancies
n = a number less than the total number of vacancies or interstitials
T = K
k = Boltzman's constant
W_1 = the linear term in the energy of a lattice defect under hydrostatic pressure P
$= \alpha Pa^3$
where $\alpha \cong -0.1$

W_2 = the quadratic term in the energy of a lattice defect under hydrostatic pressure P
$= \frac{1}{2}\delta P^2a^3/K$
where $\delta \cong$ unity and K = the bulk modulus

This formula is extremely hard to evaluate and no experimental verification is available.

2) Structural changes, in which dislocations are enabled to overcome obstacles or are caused to regroup among themselves by thermal spikes or by the absorption of point defects.

3) Constitutional changes, in which alloying elements and impurities are redistributed (accompanied in some cases by changes of phase) by spikes and point defects.

In both of the above two mechanisms either spike formation or self-diffusion would be rate controlling. Thomas reports that radiation has little effect on diffusion (15). At high temperatures the vacancies produced by radiation are insignificant compared to those that are thermally induced. At temperatures where the radiation produced vacancies become significant, the total number of vacancies is so small that the diffusion rate is negligible. Since the creep rate under ordinary conditions is controlled by self-diffusion which is not altered appreciably by radiation, any change in the creep rate from these two mechanisms must be produced by the production of spikes. Quantitative evidence of the effect of spikes on the creep rate is not available.

4) Chemical changes whereby new atoms are created within the material by transmutations or driven into the material in the form of fast ions or fission fragments.

5) Internal stress developed through thermal gradients or through radiation growth effects.

Though these last two processes are certainly important, experimental determination of their effect is very difficult and as yet no report is to be found.

It can be seen that much more work must be done in this important field, both theoretical and applied, before any definite conclusions can be reached.

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In testimony before the Senate, NASA has announced a comprehensive program for the development of seven new rocket vehicles. The program covers the development of five new engines. The smallest of the vehicles is the Scout, which will weigh about 35,000 pounds, stand 70 feet high and be capable of placing a 150 pound payload in orbit. It has a four stage motor consisting of an Aerojet Senior for the first stage; an improved Thiokol Sergeant for the second stage; a scale-up of the present Vanguard third stage for the new third stage; and the present Vanguard third stage for the fourth stage.

The Atlas-Able vehicle will comprise an Atlas ICBM mated to modified second and third stages of the Vanguard. The Atlas-Hustler, another of the vehicles, combines an Atlas ICBM with the Lockheed-Bell Hustler Motor which powered Discoverer I.

Two other vehicles are the Atlas-Vega and the Atlas-Centaur. The former is a three stage vehicle, combining Atlas with a Vanguard first stage and a new design third stage. Atlas-Centaur will be identical except for the second stage, which will be a new design booster having a greater specific impulse than the Vanguard engine. These two vehicles are expected to be capable of orbiting 3,000 pounds, or transporting about 750 lbs. to the moon.

Saturn and Nova are the two largest vehicles. Saturn will be a four stage arrangement, using an eight Rocketdyne motor cluster in the first stage for 1,200,000 pounds of thrust, a Titan booster for the second stage, the Centaur high-energy second stage as the third stage and finally the new design third stage of the Atlas Centaur.

Nova will have five stages. The first four will have thrusts of 6,000,000 lbs.; 1,500,000 lbs.; 80,000 lbs.; and 15,000 lbs. respectively. The assembly is estimated to weigh about $4\frac{1}{2}$ million pounds. The entire program is expected to cost about 2 billion dollars.

—from ASTRONAUTICS
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"THE JOURNAL OF THE INSTITUTE OF METALS"

THE VACUUM CASTING OF URANIUM

ACKNOWLEDGEMENT

J. Stephenson, of the Metallurgy Division, Atomic Energy Research Establishment, Harwell (temporarily with Atomic Energy of Canada, Ltd., Chalk River, Ontario), is the author of this article. It was published in the February 1959 edition of "The Journal of the Institute of Metals."

INTRODUCTION

THE increased use of refractory metals in the atomic-energy and aircraft industries has, during the past decade, resulted in the application of vacuum techniques to large-scale metallurgical processes.

Uranium was perhaps the first metal to be melted and cast under vacuum on an industrial scale. Early work on the casting of uranium involved the use of molten barium chloride as a protective layer on the melt. This decreased oxidation of the uranium, but some entrapment of the chloride invariably occurred during pouring, and inclusions were produced in the castings. This resulted both in the rejection of castings for inclusion defects and an increased neutron-absorption cross-section for the accepted material.

While these considerations probably had a major influence on the decision of the United Kingdom Atomic Energy Authority to develop a pilot-scale vacuum-casting unit, several other advantages were expected. Among these were a reduction in the gas and volatile content of the metal, with a consequent lessening of the possibility of gas-cavity formation and an increase in purity.

FURNACE DESIGN

Consideration was initially given to a tilting-crucible-type furnace, but this was rejected as some development of a multi-mould casting technique had taken place, and it was considered that an arrangement of a crucible from which metal was bottom-poured into a tundish and thence to a mould assembly would be mechanically simpler. In addition, it had been found that some separation of the oxide and nitride occurred by flotation, and it was thought that bottom pouring might give rise to improvements in purity.

The equipment is most easily considered in three sections: (1) the vacuum heating unit; (2) the mould container; (3) the vacuum system. The assembly is shown diagrammatically in Figure 1.

The Vacuum Heating Unit

Electrical equipment capable of supplying 2200-cycle A.C. was available from another experimental melting unit and only induction heating was considered. The advantages and disadvantages of mounting the induction coil inside or outside the furnace casing were examined. If the coil were inside the casing, the heating unit could be made of steel. This design would, however, have resulted in the possibility of arcing from the coil and increased the dead space to be evacuated. If the coil were outside the casing, a non-metallic furnace casing would be necessary. Suitable silica tubes were commercially available. This arrangement offered the advantages that the coil would operate under atmospheric pressure, the heating unit volume would be decreased, and

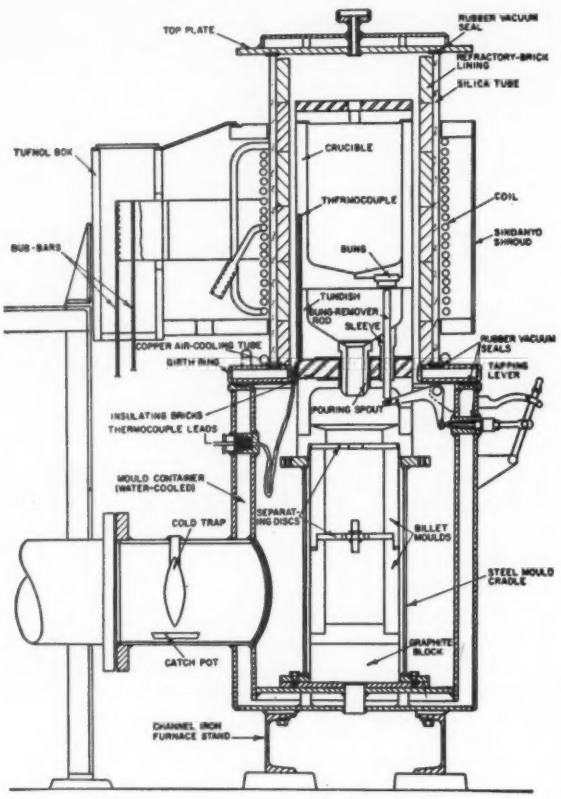

Figure 1. Billet-casting furnace.

the heating unit could be removed in one operation to expose the crucible assembly.

Because the second system eliminated the possibility of coil damage by electrical and thermal breakdown and because the refractory tube could be quickly replaced in the event of mechanical damage, the second alternative was chosen.

The vacuum heating unit (Figure 1) consists of a silica tube held top and bottom in rubber vacuum seals between a steel top-plate and girth ring, both water-cooled. These are held together outside the silica by four stainless-steel tie-rods to which eye-bolts are screwed for lifting or lowering by an overhead hoist. Water-cooling of the girth ring was inadequate to keep the lower rubber vacuum seal cool, and so, to decrease the possibility of a leak developing, additional cooling was provided by an air blast directed on to the gasket from a copper tube almost encircling the joint. (A complete ring cannot be used as it would be heated by induction.)

To decrease heating and eventual devitrification of the silica by thermal radiation from the crucible, a lining of refractory brick was fitted. It had been intended to use sillimanite, but because of delivery difficulties a silica-based brick was used and proved satisfactory over long periods of service.

The silica tube is surrounded by a water-cooled copper induction coil. The coil and the greater part of the tube are shrouded in a Sindanyo case to protect the operator against breakage of the silica and to prevent accidental contact with the live coil. A warning bulb on the Sindanyo case is lighted by induction when power is switched to the coil and the busbar connections to the coil are covered by a Tufnol box which has to be closed and locked before the coil can be energized.

A sighting hole in the center of the top-plate was covered by a glass plate on a rubber seal and used for observation of the contents of the crucible or for fitting a top thermocouple or radiation pyrometer. This proved of little value in routine operation, and the glass plate is generally replaced by a steel disc.

For reasons of operational procedure, two sizes of unit were employed. The larger carried a silica tube of 16 in. internal dia. × 31 in. high, and the smaller a tube of 12½ in. internal dia. × 29 in. high. The wall thickness of the silica was ⅜ in. in both cases.

The Mould Container

The mould container (Figure 1) is a double-walled cylinder of welded construction, of 20 in. internal and 24½ in. external dia., made from ⅜-in.-thick mild-steel plate. The depth of the vessel is 8 ft. to enable long castings to be made. Steel mould carriers or cradles can be fitted to permit operation with shorter assemblies. A locating spigot at the bottom of the container ensures that a cradle is located centrally. The top face of the container is accurately and finely machined, with a circumferential channel which carries the rubber gasket sealing the joint between the vacuum heating unit and the container. As this is the only major joint broken intentionally in the cycle of operations, its importance is obvious. When the heating unit is lowered on to the mould container, correct positioning is ensured by wheels fixed to the top-plate and girth ring. These wheels run on two vertical stainless-steel guide posts held in brackets welded to the mould container.

A lever mechanism operating a push rod through a Wilson seal in the side of the container enables the operator to lift the sealing bung from its seat on the bottom of the crucible.

The Vacuum System

(a) Pumping System

In the original construction of the furnace, two H.6 oil-diffusion pumps were connected in parallel to the mould container by a 10 in.-internal-dia. mild-steel manifold. These pumps were backed by a 100-ft.^{3}/min. Kinney pump. As described later, the original diffusion pumps proved inadequate and were replaced by a B.6 booster diffusion pump.

The size of the pumps chosen was somewhat arbitrary, as no operating experience existed. The prime requirement was that the pumps and manifolds should be adequate to evacuate the system rapidly

and to maintain a furnace pressure during operation that was low enough to assist escape of volatile constituents from the metal. The system finally used was capable of reducing the pressure to less than 5 μ in 30 min.

All the vacuum pumps are water-cooled and the exit water runs through a bucket-type relay system which switches off the power if the water flow falls below a preset minimum.

Three valves enable the system to be roughly evacuated by the mechanical pumps, further evacuated by the diffusion pump, and if necessary, isolated from both pumps (Figure 2). The original valves on the backing line were of a bellows type, but these leaked after two or three months' operation owing to failure of the bellows. They have been replaced by globe water valves modified by soldering the salient joints (Figure 3) to vacuum tightness. These valves are comparatively cheap and robust and have proved very successful.

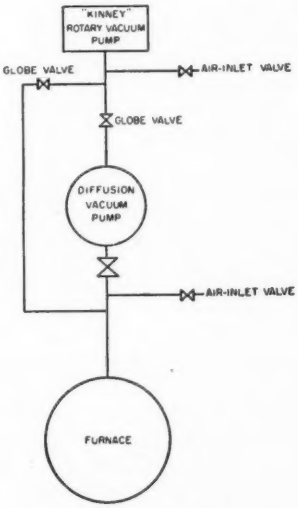

Figure 2. Circuit diagram.

(b) Pressure Gauges

Pressure in the evacuated system is measured by thermocouple gauges operating in the range 1-1000 μ. Three gauges are fitted in the following positions: (1) the wall of the 10-in. manifold (this indicates the pressure in the furnace); (2) the backing side of the diffusion pump; (3) the foreside of the mechanical pump.

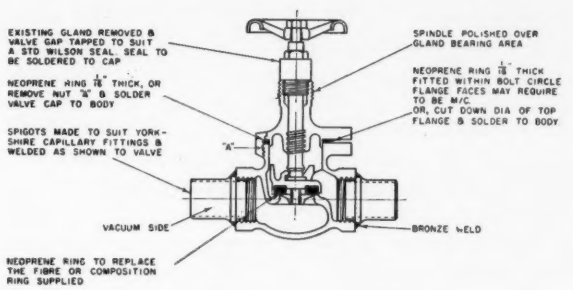
EXISTING GLAND REMOVED & VALVE GAP TAPPED TO SUIT A STD WILSON SEAL. SEAL TO BE SOLDERED TO CAP
NEOPRENE RING ⅛" THICK, OR REMOVE NUT "A" & SOLDER VALVE CAP TO BODY
SPIGOTS MADE TO SUIT YORKSHIRE CAPILLARY FITTINGS & WELDED AS SHOWN TO VALVE
VACUUM SIDE
NEOPRENE RING TO REPLACE THE FIBRE OR COMPOSITION RING SUPPLIED
SPINDLE POLISHED OVER GLAND BEARING AREA
NEOPRENE RING ⅛" THICK FITTED WITHIN BOLT CIRCLE FLANGE FACES MAY REQUIRE TO BE M/C OR, CUT DOWN DIA OF TOP FLANGE & SOLDER TO BODY
"A"
BRONZE WELD

Figure 3. Globe-valve assembly.

CASTING ASSEMBLIES

A wide variety of castings has been made with the furnaces, the size of heating unit depending on the weight of charge required. Generally speaking, the larger unit is used for charge weights above ~70 kg.

The reactivity of uranium imposes severe limitations on the choice of crucible material, and although several refractory oxides are possible from thermodynamic considerations, conditions of thermal shock, availability, and price resulted in the choice of graphite for the majority of the components of the casting assemblies. The components are generally so designed that heating of the melt above ~1400°-1430°C is unnecessary.

Billet Casting

The larger unit has often been used for the casting of cylindrical billets of metal for subsequent fabrication or remelting. Figure 1 illustrates a typical casting assembly for this second purpose.

The crucible is sealed by a graphite bung which is lightly lapped to the seat of the pouring hole. When the bung is raised by operation of the tapping lever, the molten uranium flows into a graphite tundish which serves to centralize the flow, and then through a pouring spout on to a graphite separating disc covering the top mould. A small head of metal builds up on this disc and helps to create a more uniform feed of metal to the moulds below. In the illustration, the separating disc between the two moulds has four ½-in.-dia. pouring holes equally spaced round a central graphite rod which is pegged in position. This rod is eventually drilled out of the ends of the two ingots, leaving holes which permit easy handling by the insertion of an expanding tool. For large castings, graphite is used as a mould material.

Each of the two billets illustrated weighs 70 kg., but it will be readily appreciated from the figure that considerable alterations are possible in both size and shape of the casting produced.

The standard charge for this unit is about 150 kg., but this can be increased by modifications to the crucible length and careful packing of the charge.

Bar Casting

This is typical (Figure 4) of several types of multi-mould casting operation for which the furnace has proved suitable. The crucible assembly is supported on a steel hood. The uranium stream, centralized by the tundish, runs on to a graphite distributor plate and is retained by a header cylinder recessed into

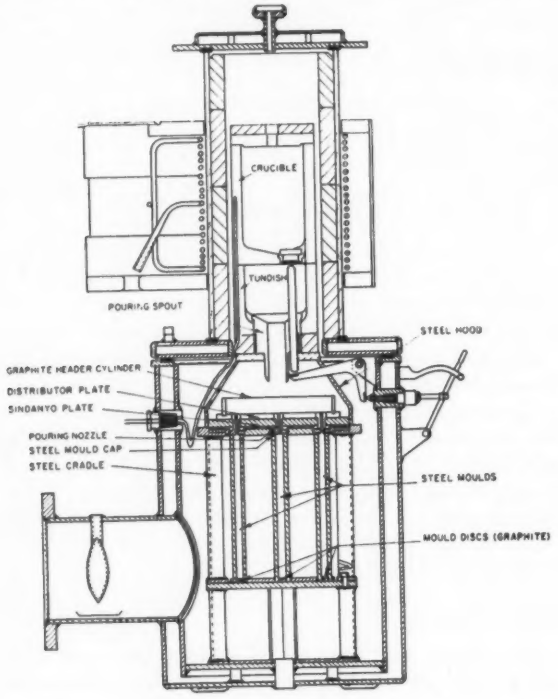

Figure 4. Bar-casting furnace.

the plate. The plate is supported on a Sindanyo sheet held in a steel tray which in turn rests on the mould cradle. The distributor plate is connected to the moulds by graphite nozzles which fit into steel caps on the top of the mould. A point of interest in mould design is that no special provision is necessary for the venting of the moulds.

EXPERIMENTAL WORK

As it was intended to use this type of furnace for both experimental casting and pilot-scale production work, initial experiments were designed to establish the relationship between the two major variables—temperature and pressure.

Temperature Measurement

The casting temperature is measured by a platinum/platinum -13 per cent rhodium thermocouple in the side wall of the crucible. Although partially shielded by twin-bore alumina tubing, the thermocouple wires failed by embrittlement during almost every cast. Some improvement could be obtained by surrounding that part of the couple liable to be above ~1000°C in a closed-ended alumina sheath, but difficulties of supply which existed at that time prevented the regular inclusion of this protection in the assembly. Consequently, a long length of wire was used, and the hot junction renewed after clipping away the embrittled metal. This ensured that the results were reproducible and that the thermocouple lasted for the melting period. The ends of the thermocouple wires were attached to rods of compensating lead material which were fitted into a rubber vacuum seal in the wall of the mould container and were connected to a recording potentiometer by a compensating lead.

Twenty melts were made in which the crucible was fitted with both a precious-metal couple and a tungsten/molybdenum couple, though the latter proved unreliable as a result of contamination occurring in the furnace. As adequate sheathing could not then be provided, the use of base-metal couples was discontinued.

To establish the significance of the temperature indicated by the couple in the side of the crucible, a second couple was shielded by a mullite sheath closed at one end and fitted through a rubber seal temporarily mounted in the sighting hole above the crucible. The lower part of the mullite was surrounded by a closed graphite tube whose lower end rested on the solid uranium which had been charged into the crucible. After the uranium had melted, the mullite was pushed down so that the couple was below the metal surface and the temperature taken.

The couple in the crucible wall indicated a temperature ~150°C higher than that in the center, when the metal was solid. Figure 5 shows a typical curve of the temperatures for a side-fitted thermocouple

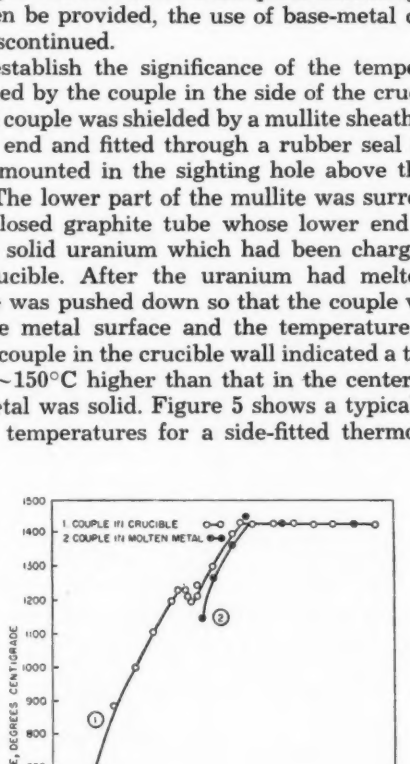

Figure 5. Heating curves for bar-casting furnace.

and results obtained from a couple in the molten metal. The former shows the melting point ~70°C higher than the true melting point for uranium. This is because a large fraction of the heat is induced in the graphite crucible. After the uranium has melted, the heat transfer improves and the differences between the two couples is small, virtually disappearing when the temperature of the melt is held constant.

Pressure

With the original installation of one Kinney pump backing two H.6 diffusion pumps, a high vacuum could not be maintained at the casting temperature owing to the evolution of gas in the system. The three possible sources of gas were: (*a*) the metal charge; (*b*) the graphite; (*c*) the refractory lining.

In several experiments empty crucibles were heated to the casting temperature of 1430°C. Both AGR and AGX qualities were tested, and the pressure at temperature was always in the range 300-500 μ. This was not significantly altered when a metal charge was included.

No decrease in pressure resulted from holding a temperature for periods up to 1 hr. and the pressure increased if the temperature was raised. A sample of the gas in the furnace was absorbed on charcoal cooled in liquid nitrogen, and was found to be air. The evidence suggested that the gas was evolved either from the heating of the refractory brickwork by radiation, or from the graphite, or both.

The H.6 pumps were replaced by a single B.6 booster diffusion pump with which a pressure of about 20 μ could be obtained before casting. A further refinement was the installation of a cold trap in the main pumping line as the Kinney pump became inefficient after a series of melts owing to water contamination of the coil. A small copper vessel was brazed into the main manifold and kept full of acetone and solid carbon dioxide during furnace operation. While some of the water no doubt originated from the combination of hydrogen from the uranium with air in the system, the majority came from the refractory lining. This was slightly hygroscopic and adsorbed moisture when the furnace was open to the atmosphere. The inclusion of the cold trap in the circuit further reduced the pressure on the furnace to less than 5 μ at the casting temperature.

On casting, the indicated pressure invariably rises to the maximum shown by the thermocouple gauges (i.e. 1000μ) because of gas evolution from the agitated metal and from the suddenly heated parts of the mould assembly. With continued pumping the pressure falls quite rapidly to between 1 and 5μ.

These early studies gave confidence in the use of the equipment, established the casting pressure obtainable as ~5μ, and permitted the continuation of a run on a time basis if thermocouple failure occurred before steady conditions were obtained.

DETAILED DESIGN OF COMPONENTS

The design of some of the components was fairly critical and these are described in detail. The remainder can be varied considerably without greatly affecting the quality of the castings produced.

The Crucible Bung

It is important that this be completely tight to molten uranium but easy to lift. As can be seen from Figures 1 and 4, any dripping of molten metal is likely to freeze the bung-remover rod in position and prevent tapping of the crucible. A design suitable for most operations is shown in Figure 6.

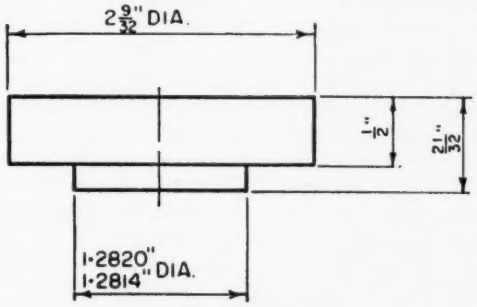

Figure 6. Graphite bung.

The spigot is short and is a slack fit in the pouring hole of the crucible. The flat mating surfaces are easily lapped into position by hand, and care is taken during assembly that no graphite dust separates them. On tapping the metal, the bung-remover rod is held in the aperture to prevent the vortex from drawing the bung back against the seat.

The Tundish and Pouring Spout

These components serve both to centralize the flow of metal from the crucible and to align the bung-remover rod with the bung. The bore of the pouring spout is of greater area than the effective area of the crucible hole. If there is any hold-up of metal here, there is a possibility of the last driblets freezing on the inside of the spout and linking it with the solidified "head" below. This invariably results in breakage of the spout when the assembly is dismantled.

The Pouring Nozzle

This component connects the distributor plate to the moulds in multi-mould casting, and the type shown in Figure 7 has been used for the casting of

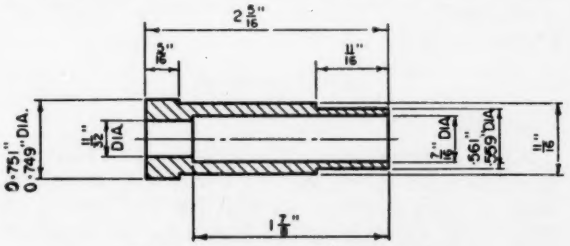

Figure 7. Graphite pouring nozzle.

solid bars. The original design was a plain cylinder with a parallel-sided hole along the axis, but as freezing of the metal occurred in some cases the design was changed to that shown so that the molten uranium is in contact with a graphite length of only 9/16 in.

Both the nozzle diameter and the head of metal above it are important in producing a parallel-sided stream that neither splashes excessively nor pours too slowly. The variables in determining the optimum conditions are many, and although some useful indications were obtained by experiments with mercury, most of the work had to be done under the expected operating conditions.

The nozzle was so designed that its top could be depressed below the top surface of the distributor plate, and turbulent pouring occurred when the depth of the resulting well exceeded ⅝ in. The optimum depression was finally established as ~¼ in. This use of a well is an alternative to charging extra metal and leaving a thicker disc on the distributor plate after pouring, i.e., it is a factor in the economics of operation and not a technical necessity.

Several diameters of pouring hole were tried, and 11/32 in. was selected as the best, although this was not very critical over the limited range tested.

The Crucible

As graphite is normally available as solid extrusions, a major part of the expense of a crucible is the cost of machining, and every effort is made to use each crucible for several melts. As a first step, the furnace is generally unloaded while the crucible is at 700°-800°C and the hot components loaded into dust-bins. The uranium left in the crucible burns quietly to oxide and, when cold, is removed from the crucible by a vacuum cleaner. As the seat is generally not re-usable, two techniques have been developed to replace it. In large crucibles a tight-fitting sleeve is used and the bung mated to the sleeve. After use, the sleeve is replaced and a bung lapped to the new sleeve.

The dimensions of the smaller crucible make this technique more difficult. Instead, in the original manufacture of the crucible three equally-spaced pouring holes are drilled. Two of these are closed with tight-fitting graphite bungs and the standard loose bung is fitted to the third. After use, one of the tight-fitting bungs is replaced by a loose-fitting bung. Repetition of this procedure ensures that the small crucible can be used at least three times.

MOULD DRESSING

Technique

Although graphite moulds had proved satisfactory, their life was not long, and mild steel was selected as being a more durable material for the making of fairly large numbers of small castings. As uranium and iron form a eutectic melting at 725°C, a mould dressing was essential. Alumina was chosen and the following coating technique was developed.

A mould heated to ~150°C in a small oven is removed and allowed to cool to ~70°C. It is then held vertically and a plunger, consisting of six felt discs screwed to the end of a thin steel rod, is inserted from the mould bottom and held with the disc about ¾ in. from the mould top. A slurry of alumina with water is poured in until level with the mould top, and the plunger is lowered slowly and steadily. Drying is assisted by blowing warm air from a hair-dryer through the tube.

Preparation of the Alumina

The ease of application of the dressing and the quality of the surface of the castings are dependent on the particle size of the alumina used, and for all this work the alumina was ball-milled to a particle size of $< 10\mu$.

To prevent surface porosity in the castings, it is essential that the mould dressing does not evolve gas at the temperature of the molten uranium. As an obvious source of gas arises from adsorption of any liquid with which the slurry is made, an investigation of the adsorption of water by alumina particles was undertaken by the Ceramics Section of the Metallurgy Division at Harwell. The general conclusions of this study were:

(*a*) For the same conditions of alumina particle size and atmospheric humidity, moisture pick-up by the alumina decreased as the calcination temperature of the alumina increased.

(*b*) Moisture is both chemically and physically adsorbed, and the tendency for chemical combination decreases as the calcination temperature increases.

(*c*) The total adsorption for a given particle size is a function of the atmospheric humidity and the exposure time.

Statistical experiments were made to establish the relationship between mould dressing and the incidence of porosity in castings. The following general conclusions were drawn:

(*a*) The thinner the dressing applied, the better the quality of the casting. In practice, a mixture of one part by volume of alumina is mixed with two of water.

(*b*) The higher the calcination temperature of the alumina, the better the quality of the casting. In the limit, fused alumina should yield the best results, but this material is not wetted by water and therefore does not form an adherent coating on the mould. It is also difficult to mill. A calcination temperature >1500°C was chosen and calcination was followed by ball-milling for 24 hr.

(*c*) The alumina should be stored in sealed containers. A progressive deterioration with time was found and, to avoid exposing large quantities of freshly calcined and ball-milled alumina to the atmosphere, the material in current use for mould coating was stored in Kilner jars.

(*d*) No significant improvement was produced by reheating the moulds after coating, when solid bars were being cast. When the castings were thin-walled hollow cylinders, a graphite core was used and reheating after mould coating was necessary to decrease outgassing from the core when the metal was poured. After coating, moulds should be loaded into the casting furnace as soon as possible, preferably within ½ hr.

(*e*) Steel moulds that have not been in use for some time should be heated to 500°C to dehydrate any iron oxide which may have formed.

TYPES OF CASTING MADE

The mould container had deliberately been made large enough to accommodate a variety of mould shapes and sizes. During the first two years of operation, two pilot-scale programs were run. The first produced a complete charge for BEPO, the experimental reactor at Harwell, in the form of cast bar which was subsequently machined to size. The precision of casting into steel moulds was determined, and it was established that solid bar of about 1 in. dia. could be cast within a tolerance of ±0.0033 in.

Castings for reactor purposes have to meet stringent inspection standards particularly for surface defects and total uranium weight. The allowances for the latter were based on a density of 18.7 g./c.c. and machining tolerances.

For cylindrical machined bars rejection for surface defects totalled about 3 per cent and for all other reasons about 0.2 per cent.

The casting techniques were then extended to the precision casting of hollow cylinders for a sub-critical assembly experiment. The type of mould used is shown in Figure 8. A steel outer mould contains a graphite core. It was essential to heat the graphite cores to 500°C after alumina coating and immediately before assembly of the mould and core. About 2000 cylinders were made of dimensions 1.640 in. outside dia. ±0.008 in., 1.300 in. internal dia. ±0.0035 in., and it was concluded that greater accuracy in mould manufacture could reduce the tolerance on the outside dia. to ±0.006 in.

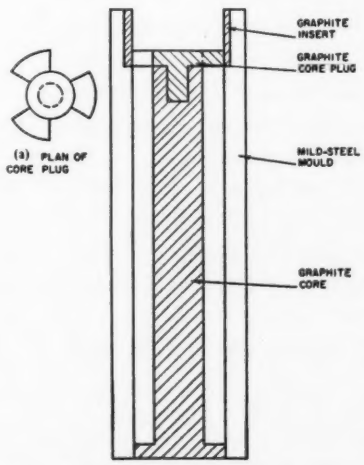

Figure 8. Steel mould with graphite core and core plug in position.

As a development of the bar-casting technique, the mould length was extended and several multi-mould casts demonstrated the feasibility of making bars of the size eventually used in the Calder Hall reactors. An interesting extension was a single run made to demonstrate the probable limits of the bar-casting technique. In this a steel mould was supported directly under the tundish and a bar 4 ft. 6 in. long by ⅝ in. in dia. was cast successfully.

Many larger castings have been made for special purposes. Right cylinders of weights up to 150 kg. present no difficulty. More interesting castings have been made generally on a "one-off" basis, for such purposes as isotope holders for radiotherapy units. These generally needed cores of some kind to decrease machining after casting and were of great assistance in establishing that the general principles of conventional casting are directly applicable to graphite moulds. Several points which are not necessarily obvious are listed below:

(1) If a split mould has to be used, one part should be recessed to mate with the other so that a direct leakage of metal is unlikely.

(2) Strapping the divided sections together can generally be avoided by recessing the mould base and the distributor top to accommodate the mould body.

(3) Molten metal should not run directly on to a core.

(4) Protection of the graphite by spraying with alumina slurry is of assistance in subsequent stripping.

(5) Outgassing of graphite moulds by heating to 500°C in air is generally desirable before loading into the vacuum furnace.

THE EFFECT OF VACUUM MELTING ON COMPOSITION

The chief effect of melting under vacuum is the reduction of chlorine content and the elimination of chloride inclusions which result from the use of barium chloride as a protective layer when melting is carried out in air. As might be expected, the hydrogen content of vacuum-cast metal is also considerably reduced, and this has resulted in the elimination of a degassing stage in the subsequent processing for reactor purposes.

ALLOYING

Similar techniques to those described can be adopted for the casting of uranium alloys. Many alloys can be charged with the uranium with no special precautions, but small additions of metallic

powders are best enclosed in a uranium tube plugged at each end with uranium. This is charged first, and any flotation effects that might prevent the formation of a homogeneous alloy are avoided. Great precautions are needed in the surface preparation of metals such as zirconium which form a very corrosion-resistant oxide film if fabricated in air. This film must be removed by pickling or by mechanical means before successful alloying is possible.

CONCLUSION

More or less continuous operation of the type of furnace described for more than eight years has confirmed the original impression that operation would be simple and clean and that the effect of substituting a vacuum for the flux cover used earlier would result in a significant increase both in the purity of the metal cast and in its "quality" in a metallurgical sense.

The bathyscaph, built and operated by Jacques Piccard, is now in operation by the U. S. Navy. Following a reconditioning program which enables the craft to probe ocean depths to 20,000 feet, the craft is beginning a series of dives to about 3600 feet, under the control of scientists of the Navy Electronics Laboratory at San Diego. After these initial dives the vessel will explore the 6500-foot deep San Diego trough and subsequently depths to the limit of its operation. Studies in underwater acoustics, thermodynamics and marine life are expected to contribute to basic knowledge of the sub-surface ocean, of vast importance in modern naval warfare.

—from SCIENCE NEWS LETTER, May 30, 1959

A cavitation tunnel commenced in Sweden in 1956 at the Swedish State Shipbuilding Experimental Tank has been completed and is now in full use. The tunnel is provided with two interchangeable test sections. The smaller one, about one-half meter square, is intended for investigation of propellers operating at low cavitation numbers. The larger one is employed for investigation of propellers in non-homogeneous wake fields. It can be fitted with complete after-body models to simulate the full scale wake field. The test sections can be rapidly interchanged. The water is circulated by a 70 HP propeller type pump. The test propeller is driven by a 21 HP, 3500 RPM motor mounted on a dynamometer table. A vacuum pump above the top part of the tunnel permits pressure control on the test section. Equipment is under construction to enable the cavitation testing of contra-rotating propellers and propellers in non-axial flow.

—from MARINE ENGINEERING AND SHIPBUILDING, April, 1959

IRVING GRANET

AN APPROACH TO THE CALCULATION OF THE TEMPERATURE DISTRIBUTION IN CYLINDRICAL REACTOR VESSELS

THE AUTHOR

was born July 2, 1924. Attended Brooklyn High School and received the degree of Bachelor of Mechanical Engineering from the Cooper Union in 1944. Employed in 1944-45 on Navy Torpedo project as project engineer on stress and vibration studies. Subsequently served two years with Air Corps overseas as Flight Engineer. In June 1948 received the degree of Master of Mechanical Engineering from the Brooklyn Polytechnic Institute and in 1949 received Professional Engineering License in New York. Since 1947, employed by Foster Wheeler Corporation as Project Engineer, Research Department; then Director of Staff Engineering, Nuclear Energy Department and later as a consultant to this department. In 1955-56 attended the Oak Ridge School of Reactor Technology at Oak Ridge, Tennessee. Has taught Heat Transfer and Thermodynamics at Brooklyn Polytechnic and is presently completing the requirements for the degree of Doctor of Mechanical Engineering. Has published over thirty articles on gas properties, heat transfer thermodynamics and applied mechanics. He is presently on the Scientific Research Staff of Republic Aviation Corporation.

THE design of pressure vessels for use in nuclear plants presents many problems that are not usually encountered in "conventional" power plant equipment. As an example, the reactor vessel is subjected to internal pressure and temperature gradients due to both heat losses to the surroundings and internal heat generation. The recently approved ASME Code Case No. 1234, "Proposed Case for Allowable Stresses in Nuclear Reactors," requires that the stresses due to pressure, external loads, etc. be combined with thermal stresses due to temperature distributions at any level of steady power operation, including internal heat generation. Temperature gradients arising from heat losses to the surroundings can be handled by the designer in a relatively easy manner (references 4 and 8) but those due to internal heat generation are not readily calculable. The major difficulty for the designer usually arises from the fact that the methods of calculation are not completely satisfactory, there is a lack of detailed information regarding the interactions and processes involved, and such calculations are long, and tedious. As a consequence it is first necessary to briefly look at those processes of importance arising from interactions of particles and ionizing radiation with materials in order to approach a reasonable engineering solution.

In the self-sustaining nuclear fission process, relatively large amounts of energy are released in many different processes in the core. Of all of these many processes, it is only certain ones that will give rise to heating in the pressure shell of interest. Chapman

(reference 1) enumerates them and briefly they are as follows:

1. *Prompt Fission Gammas:*
   When a fertile atom undergoes fission, a portion of the energy release appears immediately as gamma radiation. This radiation may reach the pressure shell and be deposited there in the form of heat.
2. *Fission Product Gammas (Delayed Gammas):*
   After fission, some of the resulting fragments are radioactive and emit gamma radiation with characteristic half lives.
3. *Inelastic Scattering of Fast Neutrons:*
   In this type of interaction of a neutron with a nucleus, momentum of the particles is conserved but the kinetic energy is not conserved. Inelastic scattering energy of the neutron is relatively large before this interaction is possible.
4. *Elastic Scattering of Fast Neutrons:*
   In the collision of a neutron with a nucleus, the particles involved rebound much as struck billiard balls and both kinetic energy and momentum are conserved in the process. The struck particle is left in an excited state and the neutron is degraded in energy.
5. *Fast Neutron Capture Gammas:*
   Upon the capture of a fast neutron in the region under investigation, gamma radiation is released and may be deposited locally.
6. *Thermal Neutron Capture Gammas:*
   After undergoing collisions of type 3 or 4 above, a neutron may reach an energy level corresponding to room temperature. Such a neutron is said to have been thermalized and at this energy level most materials have large probabilities for capturing neutrons. If this capture does not result in fission, a compound nucleus is formed and a gamma emitted. This will occur in the vessel walls due to leakage of thermal neutrons from the core or due to thermalization in the walls of low energy neutrons.

Of the many other reactions that occur and involve other particles and electro-magnetic radiation, none are of consequence in the heating of the pressure shell (reference 2). This is not to say that they are to be neglected; indeed for other reasons they are very consequential and must be considered in computations.

From the foregoing, it is reasonably obvious that a knowledge of the gamma and neutron currents reaching the vessel walls is required. In addition, one must be able to statistically predict the number and type of interactions to be expected. Such information is a function of the core, its geometry, the materials used, operational power level, etc. This information can only be developed in a given case (with any assurance of accuracy) after detailed core calculations have been made. With the exception of the most rudimentary type of critical calculations, this work is usually performed by a physics group and is a multi-group machine calculation. Chapman has made certain simplifying assumptions for an aqueous homogeneous system with a spherical core vessel. His results are shown on Figure 1 and it will be noted that curve A very closely approximates the calculated total heat generation of curve B. Curve A is exponential and over-estimates the heat generation at the inner sur-

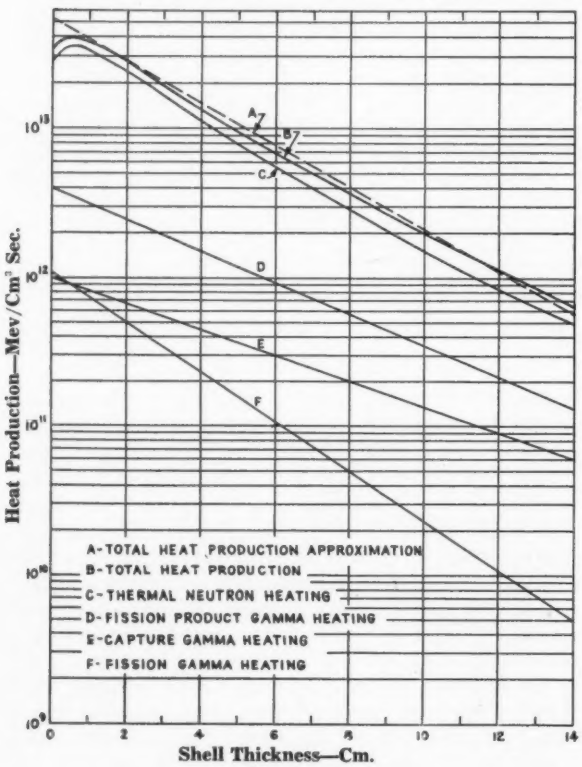

Figure 1.
Heat Production in Vessel Wall

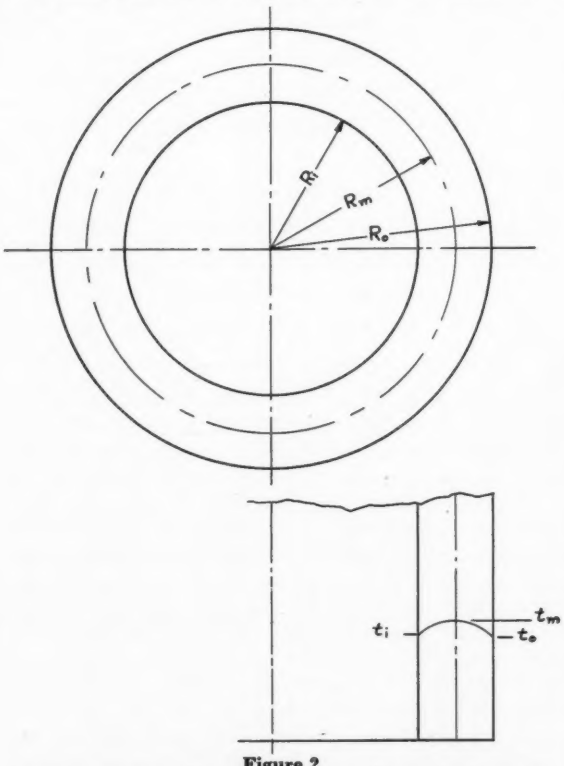

Figure 2.
Assumed Temperature Distribution in Cylindrical Reactor Vessel.

face. The assumption of an exponential attenuation of the total heat absorption has been made by most authors because this represents a good approximation and greatly simplifies subsequent mathematical operations (references 1, 5, 6 and 7).

From an engineering standpoint it is possible to obtain the temperature distribution (and stress levels) in a reactor vessel if the heat absorption at the inner face and the rate of attenuation of the heat absorption are known. For the case of cylindrical vessel two approaches will be used to arrive at a solution.

Referring to Figure 2, it will be assumed that the temperature in the wall exhibits a maximum. Since $\frac{dt}{dR}=0$ at this point, no heat will cross this radius and all the heat generated to the right must leave the outer cylinder surface; all of the heat generated to the left of the maximum must leave the inner cylinder surface. Considering the area to the right of the maximum, the total heat generated to any radius R is:

$$Q_t=\int_{Rm}^{R} Q_o' e^{-\mu R}\, 2\pi R\, dR \qquad \ldots\ldots(1)$$

From Fourier's Law, the total heat crossing a plane and the temperature gradient at the plane are related:

$$Q_t=-kA\frac{dt}{dR} \qquad \ldots\ldots(2)$$

Combining equation (1) and (2) yields the following differential equation:

$$\frac{dt}{dR}=-\frac{\int_{Rm}^{R} Q_o'(e^{-\mu R})2\pi R\, dR}{k\,2\pi R} \qquad \ldots\ldots(3)$$

Performing the integration:

$$\frac{dt}{dR}=\frac{Q_o'}{Rk}\left(\frac{e^{-\mu R}}{\mu}\right)\left(R+\frac{1}{\mu}\right)-\frac{Q_o'}{Rk}\left(\frac{e^{-\mu Rm}}{\mu}\right)\left(R_m+\frac{1}{\mu}\right) \qquad \ldots\ldots(4)$$

In order to simplify the above expression, let

$$C=\frac{Q_o'}{k}\left[\frac{e^{-\mu Rm}}{\mu}\right]\left(R_m+\frac{1}{\mu}\right) \qquad \ldots\ldots(5)$$

Equation (4) can thus be rewritten as:

$$\frac{dt}{dR}=\frac{Q_o'}{Rk}\left(\frac{e^{-\mu R}}{\mu}\right)\left[R+\frac{1}{\mu}\right]-\frac{C}{R} \qquad \ldots\ldots(6)$$

Integrating equation (6) between the limits from t_m to t corresponding to R_m and R gives the following:

$$t-t_m=-\frac{Q_o'}{\mu^2 k}e^{-\mu R}\Big|_{Rm}^{R}+\frac{Q_o'}{\mu^2 k}\int_{Rm}^{R}\frac{e^{-\mu R}}{R}dR-C\ln R\Big|_{Rm}^{R} \qquad \ldots\ldots(7)$$

Expanding equation (7) between the indicated limits and rearranging terms yields:

$$t_m-t=\frac{Q_o'}{\mu^2 k}e^{-\mu R}-\frac{Q_o'}{\mu^2 k}e^{-\mu Rm}+C\ln\frac{R}{R_m}-\frac{Q_o'}{\mu^2 k}\int_{Rm}^{R}\frac{e^{-\mu R}}{R}dR \qquad \ldots\ldots(8)$$

Equation (8) is a solution to the temperature distribution at any radius to the right of the maximum temperature. However, the last term in equation (8) cannot be integrated in terms of elementary functions. In order to evaluate it, the following identity can be used:

$$\int_{Rm}^{R}\frac{e^{-\mu R}}{R}dR=\int_{Rm}^{\infty}\frac{e^{-\mu R}}{R}dR-\int_{R}^{\infty}\frac{e^{-\mu R}}{R}dR=\int_{\frac{Um}{\mu}}^{\infty}\frac{e^{-U}dU}{U}-\int_{\frac{U}{\mu}}^{\infty}\frac{e^{-U'}}{U'}dU' \quad \text{where } U=\mu R \text{ and } U'=\mu R$$

In the form given in equation (9), the integrals $\int_{\frac{Um}{\mu}}^{\infty}$ and $\int_{\frac{U}{\mu}}^{\infty}$ are known

as the "Exponential Integrals" and values are tabulated for these integrals in reference (1).

In order to make the solution complete, another heat balance can be written to the right of the maximum and noting that all of the heat generated to the right must leave the outside surface, the following is obtained:

$$\int_{Rm}^{R} Q_o'\left(e^{-\mu R}\right)\left(2\pi R\right)dR = h_i\, 2\pi R_o\,(t_o - t_{fo}) = -kA\left.\frac{dt}{dR}\right|_{@R=R_o} \quad \ldots\ldots(10)$$

Integrating between limits:

$$\frac{Q_o'}{R_o}\left[-e^{-\mu R}\left(\frac{R}{\mu}+\frac{1}{\mu^2}\right)\right]_{Rm}^{Ro} = \frac{-Q_o'}{R_o}\left[e^{-\mu R_o}\left(\frac{R_o}{\mu}+\frac{1}{\mu^2}\right)-e^{-\mu Rm}\left[\frac{R_m}{\mu}+\frac{1}{\mu^2}\right]\right.$$

$$= h_o(t_o - t_{fo}) = -k.\left.\frac{dt}{dR}\right|_{@R=R_o} \quad \ldots\ldots(11)$$

Rearranging equation (11) and using the notation:

$C_1 = e^{-\mu R_o}\left[\frac{R_o}{\mu}+\frac{1}{\mu^2}\right]$, a more useful form of equation (11) is obtained:

$$-\frac{Q_o'}{R_o}\left[C_1 - e^{-\mu Rm}\left(\frac{R_m}{\mu}+\frac{1}{\mu^2}\right)\right] = h_o(t_o - t_{fo}) = -\,k\left.\frac{dt}{dR}\right|_{@R=R_o} \quad \ldots\ldots(12)$$

Equations (8) and (12) constitute the necessary equations for the solution to the right of the maximum. For the section of the cylinder to the left of the maximum, the same approach yields equations (13) and (14) which are analogous to equations (8) and (12) as follows:

$$t_m - t = C\ln\frac{R_m}{R} - \frac{Q_o'}{\mu^2 k}\left(e^{-\mu Rm}\right) + \frac{Q_o'}{\mu^2 k}e^{-\mu R} + \frac{Q_o'}{\mu^2 k}\int_R^{Rm}\frac{e^{-\mu R}}{R}dR \quad \ldots\ldots(13)$$

$$\text{and} \quad -\frac{Q_o'}{R_i}\left[e^{-\mu Rm}\left(\frac{R_m}{\mu}+\frac{1}{\mu^2}\right)-C_2\right] = h_i(t_i - t_{fi}) = -\,k\left.\frac{dt}{dR}\right|_{@R=R_i} \quad \ldots\ldots(14)$$

where $C_2 = e^{-\mu R_i}\left(\frac{R_i}{\mu}+\frac{1}{\mu^2}\right)$

It will be noted that equations (13) and (8) are identical (with appropriate attention to the sign of the limits of the integral) with the exception of the sign of the term involving ln R. This is the only term not involving the heat generation explicitly and the sign change is a convenience to avoid negative logarithms.

Equations (8) through (14) provide all of the necessary information for the solution of a general problem of this type. For any given problem, it may not be necessary to invoke all of these equations.

The alternate solution to the problem is to solve the generalized differential equation. This aproach presents some difficulty because of the non-linear nature of the equation. The writer is indebted to Dr. Charles Zucker for the following solution.

The general differential equation for steady state heat transfer in cylindrical coordinates with exponential heat generation can be written as follows (reference 3):

$$\frac{d^2t}{dR^2}+\frac{1}{R}\frac{dt}{dR} = -\frac{Q_o'}{k}\left(e^{-\mu R}\right) \quad \ldots\ldots(15)$$

If the above equation is multiplied by R^2 and the logarithmic transformation is used (reference 8), the following results:

$$\text{Let } R=e^z,\ \ln R=Z \qquad \text{.....(16a)}$$

and

$$\frac{d^2t}{dZ^2}=e^{2z}\left(-\frac{Q_0'}{k}\right)e^{-\mu e^z} \qquad \text{.....(16)}$$

In order to solve equation (16), it is first necessary to solve for the complementary function, re: with the right hand side equal to zero. This solution is by inspection,

$$t=a+bz \quad \text{or} \quad t=y_1+y_2 \qquad \text{.....(17)}$$

where a and b are constants that have to be determined.

The particular solution for equation (16) can be determined by use of a mathematical method known as the variation of parameters. The final solution will have the form:

$$t=aF+(bz)G \qquad \text{.....(18)}$$

By application of the method of variation of parameters, it can be shown that F and G have the following values:

$$F=\frac{Q_0'}{ak}\left[\frac{-R\ln R\,e^{-\mu R}}{\mu}-\frac{e^{-\mu R}}{\mu^2}-\frac{1}{\mu^2}e^{-\mu R}\ln R+\frac{1}{\mu^2}\int\frac{e^{-\mu R}}{R}dR\right] \qquad \text{.....(19)}$$

$$\text{and } G=\frac{Q_0'}{kb}\left[\frac{e^{-\mu R}}{\mu}(R)+\frac{e^{-\mu R}}{\mu^2}\right] \qquad \text{.....(20)}$$

If equations (19) and (20) are substituted back into (18) and simplified and added to equation (17), the following general form results:

$$t=a+b\ln R+\frac{Q_0'}{\mu^2k}\int_{R_i}^{R}\frac{e^{-\mu R}}{R}dR-\frac{Q_0'}{\mu^2k}e^{-\mu R} \qquad \text{.....(21)}$$

It is relatively easy to verify that equation (21) is the solution by direct substitution into equation (15).

At this point it is only necessary to derive expressions for the constants a and b. This can be done by invoking the following boundary conditions:

$$t=t_i \quad \text{at } R=R_i \quad \text{and} \quad t=t_0 \quad \text{at } R=R_0 \qquad \text{.....(22)}$$

Substitution of these two conditions into equation (21) gives the necessary and sufficient information to solve for a and b. These then become;

$$b=\frac{(t_i-t_0)+\frac{Q_0'}{\mu^2k}(e^{-\mu R_i}-e^{-\mu R_0})+\frac{Q_0'}{\mu^2k}\int_{R_i}^{R_0}\frac{e^{-\mu R}}{R}dR}{(\ln R_i-\ln R_0)} \qquad \text{.....(23)}$$

and

$$a=t_i-\frac{\left[(t_i-t_0)\ln R_i+\frac{Q_0'}{\mu^2k}\ln R_i(e^{-\mu R_i}-e^{-\mu R_0})+\frac{Q_0'}{\mu^2k}\ln R_i\int_{R_i}^{R_0}\frac{e^{-\mu R}}{R}dR\right]}{(\ln R_i-\ln R_0)}+\frac{Q_0'}{\mu^2k}\left(e^{-\mu R_i}\right) \qquad \text{...(24)}$$

In terms of the fluid temperatures, it is possible to use the appropriate parts of equations (11) through (14) in conjunction with equations (21), (23) and (24) above. Mathematically, both solutions derived in this paper are correct. However, the user should first determine the magnitude of his problem prior to choosing an approach. It is possible that a numerical solution might be desirable if a single problem is involved. For a parametric study, equations (21) through (24) would seem to possess the greatest potential.

One further caution must be reiterated at this point. No consideration has been given to the problem of axial temperature gradients due to nonuniform axial heat generation. In a realistic problem, axial heat distribution is nonuniform and should be accounted for. The calculation of such a three dimensional problem presents much greater difficulties

from both the heat transfer and nuclear calculations than the problem considered in this paper.

ACKNOWLEDGEMENT

The writer wishes to express his appreciation for the generous assistance given by Dr. Charles Zucker and Mr. Sheldon Strauss, both formerly of the Nuclear Energy Department of Foster Wheeler Corporation. Dr. Zucker is currently a Professor at Farleigh Dickenson College and is associated with Universal Nuclear Co. Mr. Strauss is presently associated with the Sylvania-Corning Nuclear Co.

NOMENCLATURE

A = Heat transfer surface—square feet
a = Arbitrary Constant
b = Arbitrary Constant

$$C = \frac{Q_o}{k}\left[\frac{e^{-\mu R_m}}{\mu}\right]\left[R_m + \frac{1}{\mu}\right]$$

$$C_1 = e^{-\mu R_o}\left[\frac{R_o}{\mu} + \frac{1}{\mu^2}\right]$$

$$C_2 = e^{-\mu R_i}\left(\frac{R_i}{\mu} + \frac{1}{\mu^2}\right)$$

$e = 2.718 + \ldots$
h = Heat Transfer Coefficient Btu/Hr. Ft^2 °F
h_o = Heat Transfer Coefficient based on outside cylinder surface Btu/Hr. Ft^2 °F
h_i = Heat Transfer Coefficient based on inside cylinder surface Btu/Hr. Ft^2 °F
k = Thermal Conductivity Btu/Hr. Ft^2 °F/Ft
Q = Local Internal Heat Generation rate Btu/Hr. $ft.^3$
Q_o = Internal Heat Generation Rate at Inside Radius of Cylinder Btu/Hr. $Ft.^3$
Q_t = Total heat generated to any radius from the radius of maximum temperature—Btu/Hr.

$$Q_o' = \frac{Q_o}{e^{-\mu R_i}}$$

R = Radius of cylinder at any point—ft.
R_i = Inside radius of cylinder—ft.
R_o = Outside radius of cylinder—Ft.
R_m = Radius of Maximum temperature—ft.
t = Temperature °F
t_i = Temperature of Cylinder at Inside Radius—°F
t_o = Temperature of Cylinder at Outside Radius—°F
t_m = Maximum Temperature of cylinder—°F
t_{fo} = Bulk Fluid Temperature at Outside of Cylinder—°F
t_{fi} = Bulk Fluid Temperature at Inside of Cylinder—°F

$U = \mu R$
$U' = \mu R$

$z = \ln R$
$\pi = 3.141 + \ldots$

μ = Heat Deposition Coefficient $- \frac{1}{\text{ft.}}$

$y_1 = a$
$y_2 = bz$
F, G = Functions for the solution of the general differential equation—particular solutions

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SHIPBUILDING PRACTICE IN THE SOVIET UNION

THE AUTHOR

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INTRODUCTION

The evolution of shipbuilding practice within the Soviet Union has occurred as a result of the superimposition of modern needs upon inherited ideas and practices. One constant in the Soviet shipbuilding scheme of things is climate. Because of the severity of the climate, particularly in the northern part of the Soviet Union, it was common practice, prior to the advent of the Communist Party, it should be noted, for Russian shipyards, both private and government-owned, to be equipped with covered building ways, known as ellings. While the actual work of outfitting was not done under cover the basic work in building riveted ships was; the covering providing the protection from the elements so sorely needed in winter months.

For many years designers, shipbuilders, economists, and commentators have argued the pros and cons of building ways with and without cover. Additionally, the argument was concerned with whether heating of the structures was necessary. Now, within the context of modern day techniques and materials, the argument appears to have been settled in favor of covered ways, the problem of heating being decided by the geographic location of the shipyard. It is intolerable, the argument goes, to permit weather to influence building rates and to obviate the benefits derived from the use of modern types of paints, insulating materials, automatic welding and other innovations and improvements. Basically, Soviet practice attempts to establish shop-type conditions from the time the keel of a ship (merchant or naval) is laid until such time as it is launched. By use of these conditions there has evolved the serial production of all types of ships, as witness the submarine building program, the various destroyer and cruiser programs and the now extensive *KAZBEK*-class tanker building program, practically all of which have been built by use of what is called the "continuous flow-position" method of building. Disregarding the question of production efficiency or norms, interrupted schedules because of weather conditions would, obviously, be intolerable.

CLIMATIC CONDITIONS

The detrimental effect of weather on building ships is too well known to belabor. However, since much, if not most, of the shipbuilding in the United States is done in the open air, perhaps a better understanding of the problem in the Soviet Union will be had if present day Soviet views on the subject are explored.

Engineering standards for Soviet shipbuilding enterprises forbid the welding of low-alloy steels in temperatures below 5°F and similar restrictions for carbon steel welding forbid such welding below between −4 and −13°F. Ship's hulls and superstructures may not be painted when temperatures fall below 41°F. Needless to say, the restrictions imposed on painting in the rain and snow, and even in bright sunshine, cut into production schedules.

Temperature is of considerable importance with the various types of interior insulations used in the USSR and wind and frost can impose their own restrictions on the handling of machinery and equipment. Finally labor laws appear to forbid open air work at any time when the temperature falls to −13°F or lower.

LOSSES CONNECTED WITH OPEN AIR WORK

Unless covered areas are used, the shipyards must have available for use temporary coverings in case rain or snow falls; and, in any case, in winter months, provision must be made for heating in order to accomplish certain of the work inside the ships under construction.

According to calculations provided by some of the shipyards, the increase in manpower needed to meet production schedules of a given scope when the yard is an open air one is on the order of 10 percent of the total manpower for the yard's annual work program. The time lost in the course of a year because of weather conditions for open air yards reaches considerable proportions and, in general, is rarely predictable. It is only after the fact that one can arrive at the extent of the interruption to any program for any given period of time.

However, certain data for the Leningrad area, site of several large commercial-naval shipyards, suggest that work in the open will suffer at least as follows, on an annual basis:

Days with air temperature below 5°F (impossible to weld)	15
Days with air temperature below 41°F (impossible to paint)	198
Days with rain, snow, fog (impossible to paint)	147

Obviously, certain of the work involved in building ships can continue, but given the same working force, lost time cannot be made up and production schedules must either take the above probabilities into account or, as time lost piles up, alter production schedules. It is equally obvious that work going on inside the ship will be hampered, if not completely interrupted by low temperatures, with corresponding drops in productivity.

Losses of this type, it has been found, simply cannot be calculated with any degree of accuracy, but the best estimate available from Soviet sources is one which claims open air yards suffer a resounding drop of 40 per cent in worker productivity during the winter months in the northern area. It has been necessary to incorporate this fact in planning norms and, ultimately, in the final cost of the finished product. It is further estimated that, depending on the temperature in the particular area, as well as on other atmospheric conditions, these norms and costs are increased from 20 to 80 percent.

Covered building ways, conversely, are estimated to yield, annually, 10 percent more production. Since some 40 percent of all the work on a ship takes place on the ways, according to Soviet methods, increasing manhours to cover loss of production caused by weather on open ways amounts to some 4 percent of the total manhours needed to build the ship.

Too, included in the increased costs to build ships that we have already noted are the costs arising from the need to provide heat for all ships, and more particularly, those being built in the open. When the way is a permanently covered structure the heating plant is designed to heat the entire production area and the efficiency is relatively high. Open ways, however, are wasteful of heat which is provided for individual compartments in the ship, for heating the water with which tanks are tested, for heating the air pumped into compartments where welding and painting is going on, for heating the underwater part of the hull when that area is painted, for heat to maintain some sort of constant temperature so that condensation within machinery casings and housings will not generate destructive corrosive processes.

In the fall-winter period this latter problem is extremely serious, since temperatures vary widely. Equally tricky is the period when main and auxiliary machinery is being set in place in the machinery spaces and before the decks are closed up, when sudden or prolonged rain disrupts work and, at the same time, may cause unnecessary damage to such machinery. This type of decentralized heating requires the installation of larger boilers and associated equipment, larger piping, more fuel—all adding up to higher capital investments and upkeep costs.

CAPITAL INVESTMENT

The State Shipbuilding Institute, in order to establish the economic feasibility of constructing covered building ways, developed three basic types of shipyards. For each the Institute estimated the size of the investment, as well as the probable operating costs. Estimates were based on the following:

Yard A. A medium sized shipyard with a productivity of 12 units per year, the units to be designated as those having "complex" installations.

Yard B. A small shipyard with a productivity of 32 units per year.

Yard C. A medium sized shipyard with a productivity of 12 units per year, the units to be designated as those having "simple" installations.

Calculations were made for both heated and non-

TABLE B

	Heated Ellings			Open Ways With Bridge Cranes		
	A	B	C	A	B	C
Operating expenses, rubles for (annual) Heating and ventilation	915,000	145,000	626,000	2,380,000	551,000	1,474,000
Loss in condensate	28,000	4,000	19,000	402,000	93,000	250,000
Total	943,000	149,000	645,000	2,782,000	644,000	1,724,000
Capital investment for boilers, based on total steam needs	1,885,000	363,000	1,450,000	4,350,000	1,305,000	2,900,000

heated, covered ellings, as well as for open ways with either bridge or portal cranes. Included in the cost of building the open ways was the cost of erecting the building needed to house the staff to operate the yard, the cost of building warehouses and special structures used for equipment in the various parts of the yard. By contrast, the covered elling is considered to be all-inclusive in cost. Table A is indicative of Soviet ideas as to comparative costs.

TABLE A

Type of Installation	Construction Cost, Rubles, for Shipyards		
	A	B	C
Covered, heated elling	50,900,000	12,500,000	22,900,000
Covered, unheated elling	46,900,000	11,500,000	21,100,000
Open way with scaffolding and bridge cranes	38,900,000	10,200,000	16,900,000
Open way with portal cranes	59,200,000	15,800,000	25,900,000

1 Although the "international" exchange rate for the ruble is 4 to $1.00, the "tourist" rate of 10 rubles to $1.00 is probably the most realistic for conversion purposes.

It will be noted that, because the cost of portal cranes runs 50 to 70 percent of the total cost of an installation so equipped, such installations are the most expensive type of shipyard for the Soviet Union to build.

OPERATING EXPENSES

Soviet economic practices, for purposes of arriving at prices to charge the customer, vary considerably. When a product is offered for internal consumption the price may well be completely at variance with the price for the same product when such product is, say, for a customer in a country the Soviet Union is penetrating. So, when it is announced that the Soviet Union, itself a charterer of shipping space, is offering for sale cargo vessels in the 16,000-ton deadweight class at prices which appear to be attractive to the world market, we are merely observing yet another example of outright subsidy to Soviet industry to provide products for use in fostering the economic penetration now so actively engaged in by the USSR. For home consumption, however, Soviet economists have arrived at the figures in Table B to indicate the relative prices to operate various installations. Not included are wages paid when no work is done, the cost of snow removal, the construction costs for various types of hatch coverings and coverings for deck openings for temporary use, and the cost of actual time lost in the building cycle because of atmospheric conditions.

Beyond what may be designated as a basic cost, there remain the costs of repairing fixed installations and equipment and amortization costs. For the three types of shipyards we have concerned ourselves with, figures have been derived for such costs based on:

(a) for installation repairs, 1 per cent of capital investment;
(b) for equipment repairs, 4.5 percent of capital investment;
(c) for amortization, 5.6 percent of capital investment.

Table C reflects these percentages for the three basic types of shipyards under discussion.

Beyond the figures already cited, it is estimated that the annual cost for protective coverings in shipyards requiring such coverings will, for the specific shipyards listed, require expenditures of:

Yard A ..... 198,000 rubles
Yard B ..... 334,000 rubles
Yard C ..... 215,000 rubles

At the same time, the covered, heated ellings are not prone to interruptions in production due to weather so that such yards are estimated to yield an average 10 percent greater productivity and, depending on the volume of work assigned, an annual saving in

TABLE C

	A		B		C	
	1	2	1	2	1	2
Current repair						
Covered heated elling						
Installation	44,300,000	443,000	10,300,000	103,000	19,900,000	199,000
Equipment	6,600,000	297,000	2,200,000	99,000	3,000,000	135,000
Total	50,900,000	740,000	12,500,000	202,000	22,900,000	334,000
Open way with bridge cranes						
Installation	32,300,000	323,000	8,000,000	80,000	13,900,000	139,000
Equipment	6,600,000	297,000	2,200,000	99,000	3,000,000	135,000
Total	38,900,000	620,000	10,200,000	179,000	16,900,000	274,000
Amortization						
Covered, heated elling	50,900,000	2,850,000	12,500,000	700,000	22,900,000	1,282,000
Open way with bridge cranes	38,900,000	2,178,000	10,200,000	571,000	16,900,000	946,000

Column 1. Capital investment in rubles
Column 2. Cost of current repairs and amortization in rubles

wages somewhat as follows is expected:

Yard A	1,470,000 rubles
Yard B	750,000 rubles
Yard C	500,000 rubles

Overall, therefore, a balance sheet incorporating the above figures reveals that an open way shipyard costs Soviet shipbuilders an annual sum beyond that chargeable to covered, heated ellings:

Yard A	2,715,000 rubles
Yard B	1,427,000 rubles
Yard C	1,398,000 rubles

UNHEATED, COVERED ELLINGS AND OPEN WAY AREAS WITH PORTAL CRANES

Unheated, covered ellings occupy an in-between position, somewhere between the covered, heated ellings and the open way areas equipped with bridge cranes. While unheated ellings do not always ensure proper conditions for painting, for installation of insulating materials, for welding and similar processes in the building cycle, they do provide considerably better working conditions than those found in open way areas. While the State Shipbuilding Institute did no research in this field, the researchers believe that labor productivity must be higher than that which is found in open way areas, but at the same time there is a feeling that such productivity is lower than that found in the heated ellings. Hence, construction of unheated, covered ellings is recommended for those sections of the country where the climate is mild and where, particularly, the winters are neither prolonged nor severe. This type of installation is said to be particularly suited to enterprises engaged in the building of merchant ships as opposed, presumably, to the needs for building naval vessels.

SELECTION OF BASIC METHOD OF ASSEMBLING SHIPS ON WAYS

Once facilities have been provided, Soviet designers must proceed to establish methods to be used in the actual construction of a given ship, or series of ships. The designer, after taking into consideration the type of ship involved, its size and peculiarities, whether or not it is to be produced as a class, how the project fits into the program of the yard to which assigned, as well as the yards production capability, then proceeds to evaluate his design on the basis of:

1. The cooperative ties between the building yard and other plants;
2. The availability of production space;
3. The type, number of ways, and the size of the yard's frontage;
4. The type of equipment in the shops;
5. The availability of cranes and transport, as well as capacity.

The Design Bureau then selects the most suitable method for the construction of the hull and for the ship as a whole. In general, and depending on the size of the ship, this selection will fall into one of two basic methods in use in the Soviet Union, block or sectional.

Soviet experience has shown that ships displacing up to 5,000-tons can be most handily built by use of the block method, the blocks themselves consisting of several unit sections. Ships of over 5,000-tons displacement, wherein unit sections may be too heavy for the lifting and transport equipment in the yard, usually are constructed using the sectional method. There are other technical and economic factors which enter into the final determination, but, in general, lifting and transport capacities govern.

COMPARISON OF THE TWO METHODS

When the sectional method of assembling the hull is used, work is begun with small sections and interior work, including machinery installation in that particular section, is done at a later time. For example, closed sections are tested for water tightness during the preparation of a particular section and it may be only after such testing that supplementary work, such as the installation of insulation, if required, is done.

Assembly of hull blocks, when the block method is used, is carried on over a wider work front since the assembly work covers many aspects of the total at the same time. Water tightness tests can, in this case, be done in each block as soon as it is completed and all the work is done under so-called "shop conditions." Each block is equipped with fittings and machinery up to 80 to 85 percent of the total work for that particular block before it is moved to the way area. When this method is used way work consists only of putting the blocks together and tying up the loose ends to make the whole.

Beginning of construction for a ship for which the block method of assembly has been selected is the date of the setting in place of the first bottom section of the block in the transporter carriage, whereas the date of commencement for a sectionally built ship is the date when the first bottom section is set down on the ways. The date for the completion of the building cycle, in either method, is the same; the moment when the ship is ready for launching, assuming percentage of completion in either method to be the same.

As blocks are delivered to the ways for assembly into the ship as a whole they are said to be 80 to 85 percent complete in themselves. Since, on the other hand, this high percentage does not hold for the sectional method, a lag in relative readiness develops which is never, in practice, overcome. In fact, it has developed that, as a specific example, if it takes 50 days, using the block method, to get a ship ready to launch, the same ship, if the sectional method of assembly is used, will not be ready for launching for 60 days. Costwise, a ship displacing 1,200-tons, built by the sectional method, is 17 percent more expensive than one built by use of the block method. The implications, if series production is required, are obvious.

CONCLUSIONS

So far as facilities are concerned, the construction of heated ellings in shipyards, given the climatic conditions which exist in the Soviet Union, offers the best means for building and outfitting ships. It is also apparent that a considerable saving in operating expenses occurs when such installations are used, particularly when the cost to operate open ways is considered. However, while there are areas in the Soviet Union where unheated ways are practical, the construction of covered ellings, heated or unheated, is necessary in order to continue to meet the requirements for regular and steady production of ships and to further meet the requirements for the protection of labor and the need to increase the productivity of that labor.

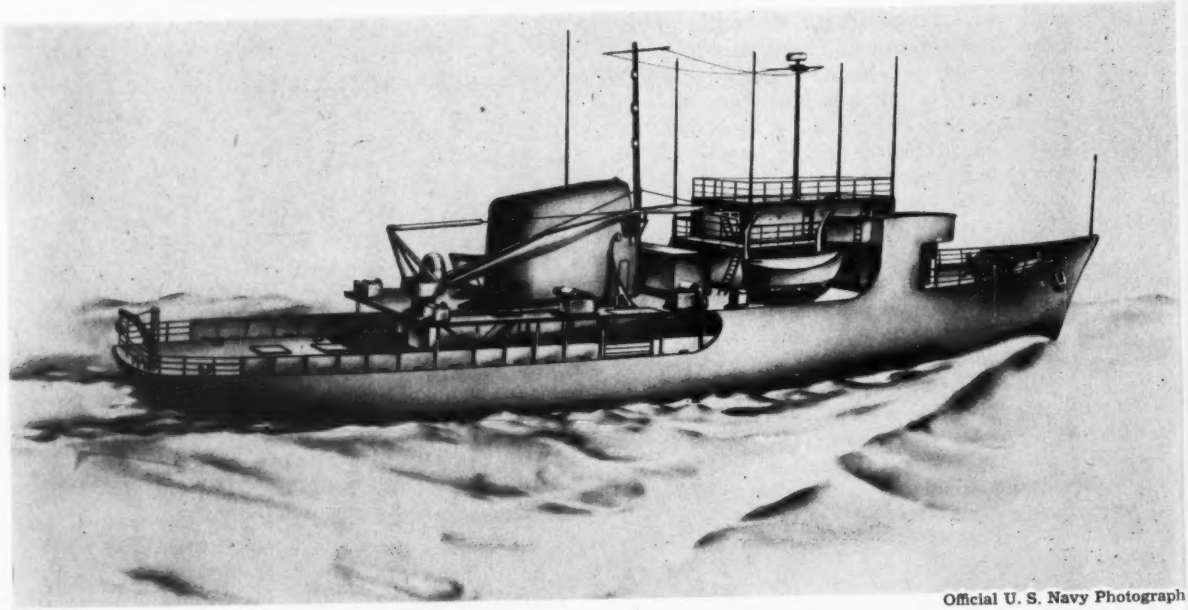
Once the facilities are available, and within the framework of the many factors involved, Soviet designers believe that, for ships of up to 5,000-tons displacement, the block method of assembly is preferable since in the use of this method of building the cycle is shorter because shop equipment and special machinery and tools are more fully utilized.

One of the most recent concepts in nuclear reactor design has been under study by the Armour Research Foundation. The fuel in this reactor is in a new form—fissionable dust carried in a gas. The gas-dust mixture passes through a reaction chamber where the presence of the moderator triggers fission, heating the mixture to a 2000-3000°F. level. Passing next into a heat exchanger, the fuel-gas mixture gives up its heat to produce steam. Most of the mixture then passes to a blower where it is returned to the reactor vessel for recycling. A small portion is diverted through a fission product removal sequence before rejoining the main steam. Advantages which appear to accrue from this concept are higher temperatures and power densities, reduced corrosion problems, high neutron economy, no fuel elements or control rods. At present major uncertainties include lack of detailed knowledge of fuel particle behavior, including wall deposit and erosion problems; lack of sufficient information regarding reactor stability; adequate compressor design; and prevention of leakage.

—from NUCLEONICS, June, 1959

Official U. S. Navy Photograph

Artist's concept of an ocean escort included in the Navy's FY 1960 Shipbuilding Program.



Official U. S. Navy Photograph

Artist's concept of an Oceanographic Research Ship, AG (OR), which is included in the Navy's FY 1960 Shipbuilding Program. It is designed to be a floating laboratory for oceanographic studies. It will be civilian manned and operated, and will have special seakeeping and operating characteristics for accomplishment of its duties.

THE 1960's NOW

ACKNOWLEDGEMENT

The staff of "Engineering" recently made a three-months' survey of British engineering firms to see how they prepare themselves for new products. The result was published in a supplement to the 17 April 1959 edition of "Engineering." Reprinted herein are a number of sections of the report. Those not included are "Information Stimulus," "Plant Guide," "Construction Prospect," "Maintenance Operation" and "Market Survey."

MANAGEMENT DIRECTION

EXPERIENCE shows that the most consistent return for a manufacturing business comes from successful product planning. In essence this means making the right product at the right time, that is one which will incorporate the most up-to-date techniques and materials and will meet the needs of the market. Since most new products or new processes take between one and three years from the development of the idea to the manufacturing stage, it is necessary to look ahead at least that much. In addition, the idea has to be born: it can be produced in a company's research laboratory, or it can be purchased from another source. If time is short the cycle can be reduced by acquiring the rights to make some other firm's products, products which interleave with one's own, or are more up to date, or are simply in rising demand, while the demand for one's own products is falling.

The purpose of this article is to suggest ways in which product planning can be made to work. Examples are given to illustrate both problems and solutions, taken from actual case histories obtained from the companies mentioned. The emphasis is on planning and organization, but this does not imply that the chairman or managing director who scours the world in search of new ideas or new things to make is wasting his time. Several of the most promising developments were introduced in that way, almost by accident. Such an interest on the part of a top executive is a welcome sign that he at least is living in the 1960's now and probably has for two or three years past. It is his job, but we suggest it is not merely his—it is his company's job, in the widest sense. Planning several years ahead is a function of management just as selling what is made, or making it efficiently. There exist for these functions fairly stereotyped organizational patterns, which may fit well or not so well, but they are accepted and so are the methods used to achieve fairly obvious objectives. This is not true of product planning, even in the most elaborate, up-to-date organizations. Wherever one goes one finds an element of the mysterious, the intangible, the trusting to luck and similar unmanagerlike attitudes.

The first essential is that a company should be "product conscious" in depth, from the chairman to the foreman or at least down to the section leaders in the drawing office and the application engineers in the sales force. If such consciousness exists two things result: *(a)* people think concretely about what the company makes and ask themselves if it is the right thing, rightly made, properly sold, etc.; *(b)* ideas flow from many quarters concerning what the company might make. There are many ways in which such product consciousness can be created, it is basically a problem of effective communication within the firm (a two-way flow), appropriate technical reading, visits to users and to exhibitions at various levels, and other activities which can be suggested and en-

couraged. Above all, however, it is example from the senior levels of management; enthusiasm on their part, active and deliberate interest in technical progress, will tend to be infectious. Thus the first task is to create interest in the senior ranks.

Heads Together

The task is to make the company product conscious. The effect of such consciousness makes all the difference between profitable growth and stagnation, or at best unprofitable groping, in any industry when the rate of technical change is high. One way of doing this which appears to be effective is to constitute a committee of executives, called the new product committee, or the design co-ordination committee, meeting once a month for a whole day. The managing director—the chairman in the case of small companies or the divisional manager in the case of large ones—is chairman of the committee. Members are the heads of departments, including sales, purchasing, accounts, drawing office, and sometimes production planning. Where a market research department exists, the manager should be a member of the committee; where it does not it is helpful to have a representative from a marketing research organization. The purpose of either is to stimulate thought and discussion from the somewhat detached viewpoint of the outsider.

A typical agenda for a first meeting would be (1) an *introductory talk by the chairman,* followed by (2) a critical analysis of *existing products* (are we making the right things now and are they likely to be the right ones in five years time? Can manufacturing costs be reduced, for example, by rationalization and increased standardization? Can they be improved technically, that is, are they correctly specified in view of advances in manufacturing techniques, materials of construction, and so on? Can sales be expanded? Are the products correctly marketed? Do they lead in their field? Are they adequately promoted? And the like); (3) *new products* (what could we add to our range or substitute for some of our products to strengthen our competitive position? Should we explore entirely new fields? What are the "growth" industries and are we supplying them?); (4) *suggestions for the conduct of the meetings;* and finally (5) *selected task for next meeting and agenda.*

The new product committee meetings should not be too formal, particularly at the start when the more silent members should receive every encouragement to play their full part. But a secretary, minutes and agreed agenda are basic necessities if the meetings are to be productive. Briefly the following are the main gains to be expected. What the firm makes is under scrutiny by seven or eight members of it, few of whom have time to think about the product policy of the firm or think themselves qualified to do so.

The accountant can be a shrewd critic of product policy. The sales manager and the works manager have to consider long-term policy together and to listen to what the chief engineer has to say. Slowly at first but with increasing impetus team work is developed and all members become accustomed to think critically and constructively about the competitive position of their company's products now and several years ahead. A recommendation made by the new product committee and accepted by the board stands every chance of implementation for it is the brain child of the whole organization. The terms of reference of new product committees vary but in most cases they act in an advisory capacity to the board. A by-product of the new product committee's activities is that the heads of departments are forced once a month to down tools and direct their thinking forward in time.

Information

The life blood of any manufacturing concern is the amount of information which is obtained from the fields in which it operates. The kind of information needed by the new product committee, or the company's board if no committee exists, falls into three parts: (1) new ideas in their own and allied fields; (2) facts on the market acceptance of these ideas quantitatively and chronologically; (3) facts on the feasibility of any project evolved from (1); and (4) an assessment of the likely profitablility of the new product or process.

The safest way to get results, and the surest way in which to avoid a flood of disconnected ideas is to define the broad fields in which the company should operate, *ab initio.* Steel and Company, who are a group of manufacturing units principally engaged in the building of mobile cranes and heating and ventilating equipment, set their targets on "growth" industries: chemicals, petrochemicals, nuclear power and petroleum. Taking into account their traditions and the fact that they had built up over the years a first-class reputation for heavy to medium fabrication in most metals, they asked themselves "what could we make that these industries need?" and set about finding out (using marketing consultants). The outcome was investment in a highly modern plant and the recruitment of a technical team enabling the company to make and market a wide range of pressure vessels and heat exchangers used in these industries. In their case the research and engineering followed the guidance obtained from a study of opportunities in certain industries.

Organization

A difficulty experienced by most firms with a will to expand into new fields is that of assessing quickly and cheaply the value of an idea—which might be a mere drawing and description, or at best a working model. A consulting organization specializing in this field has engineering staff, each of whom attempts to keep up to date in his own specialized field: this is the inner ring, or first layer, of the sieve: each engi-

neer maintains contact with specialists in an even narrower field, perhaps three or four who may be working in universities, research centers, as consulting engineers, and in other outside capacities. In addition, this firm has associates in the leading industrial countries, who are able to check on any idea originating from their country. A similar organization can be built up within a manufacturing unit, using engineers and technicians for the purpose.

The organization needed to assess the value of a manufacturing license is not very different from that required for the assessment of ideas, or of prototypes. Without such an organization and sources of information, no new products committee can operate effectively. In other words, there must be someone to do the work, and only when it has been done can the committee take the idea a step further and work out a project, setting off likely returns against likely expenditure. It is necessary to be methodical, precise and persistent, and there is in fact little in the exercise that is crystal gazing—rather is it intelligent deduction from clearly visible broad trends, interpreted in terms of an ability to translate them to good account. The point to emphasize is the need for an organization grinding steadily and in a workmanlike manner towards a preselected goal.

Research

Very little space remains for a discussion of longer-term activities, such as basic research. Relatively very few companies in engineering industries in fact do any basic research in this or any other country. Increasingly it is the field of the colossus and, it is wrong that this is so. Properly run and ably-directed even a small research department working on basic problems directly connected with the company's activities can be of great value. A good example is provided by the Export Packing Service. This is an exceptionally ideas-minded organization which was founded in 1946 to answer a need for the special packing of Government stores to preserve a state of readiness, should war break out again. They worked mainly with established packaging materials because they existed; in 1954 they formed a research company, EPS Research and Development Limited. The technical director of the firm explained that they began by asking themselves what kinds of materials they needed to carry out their functions, not whether anything better were available. They defined their needs and set about developing new substances: a new cushioning material, Avocel, which is an expanded pvc compound with a high resistance to fatigue under repeated dynamic loading; and a new type of barrier, that is wrapping material, which gives full protection whatever the climate (a lead foil faced on both sides with cloth and pvc).

These mental processes are quite basic to any forward planning, and the brains which carry them out must have *(a)* the formal organization which induces the necessary activity, and *(b)* the information without which no discerning activity can take place.

STAFF POLICY

To have the right number of people, of the right kind, in the right place, at the right time, is the object of staff planning.

The Right Number

There is a danger following a period of staff shortages that more people will be trained and recruited than can finally be used. In the view of one personnel manager, unless industry expands by a factor of three by 1965, Britain will have too many graduates; it will soon be more difficult to obtain technicians than technologists. On the other hand, any surplus of scientists may readily be absorbed in countless other jobs, such as store management, where a systematic training would prove invaluable.

The approaches of different companies to staff planning vary with the area and the product. Dowty, for example, plan their product policy as the independent variable, aiming at the greatest economy of manufacture; if insufficient labor is available, work is subcontracted out. High Duty Alloys take into consideration the availability of the various categories of labor before planning production; whereas the Glacier Metal Company, though allowing for the claims of staffing and the market at top level, may modify the actual production process to accord with the discretion and skill of the available operatives.

At High Duty Alloys the required intake of staff is assessed as far as possible in advance of production schedules by keeping a running manpower budget based on the firm's future production. An estimate is made of the total working force needed to carry out the program, allowing a percentage addition to cover normal rates of time lost. Comparison of this total with the numbers employed in each category shows how many extra employees of each kind are likely to be needed during the period of production—or how many will be redundant. This final figure is adjusted to allow for normal wastage rates.

Numbers required may be affected by the introduction of automatic methods. Thus in the highly automatic chemical industry, direct manual process labor costs can be as low as, or lower than, 5 per cent of total factory costs, as against 60 per cent in other engineering industries. A company making capital equipment, with a capital investment of £1½ million, employs 800 to 900 people; a new factory proposed will require an investment of £2 million, employ some 90 people and produce three times as much. It follows that in competing for export markets, the technical content of the production process may be as important as the technical content of the product; so automation may reduce the competitive effect of high labor costs.

So far, little preparation appears to have been made to accommodate the bulge, and most firms state that they must retain a roughly constant proportion of apprentices to total works payroll. Turnover ranges from 15 to 25 per cent, but the figure appears less

serious when seen in terms of length of service. The longer his service, the more likely is a man to stay. Simms Motor Units claim a consistent fall in staff turnover from 29 per cent in 1954 to 17 per cent in 1958. Albright and Wilson make no special effort to discourage turnover since, in their view, it helps the sifting process.

The Right Kind

Shortages of labor are particularly severe in certain categories. The Ford Motor Company, at Dagenham, for example, have, like other engineering concerns, since the war experienced a shortage of craftsmen, designers and technical staff generally; but the company's excellent training schemes are beginning to show returns and the supply of junior draftsmen has recently improved. A pressing need at present is for experienced designer-draftsmen, designers and power-house engineers. High Duty Alloys are short of first-class design men, high-grade toolroom operatives and maintenance engineers; but the position is improving. They state that diversification, requiring the design of new products, has aggravated the shortage of draftsmen.

To secure the necessary draftsmen, Dowty set up a short-term training school, which took people of any age, from inside or outside the company, from operatives to clerks, and trained them over a period of 8 or 9 months to become detail and modification draftsmen, thus releasing qualified men for more taxing work. At the same time they set up a drawing office in London, where draftsmen, like gold, were thought to be plentiful. It has now been closed. The decision of many firms to set up similar establishments, for a time at least, disturbed the market. F. Perkins placed their extra drawing office in the Midlands with the same object. Dowty also advertised in Canada offering to pay the passages to England of skilled immigrants if they were willing to return to this country under a two-year contract. Some 12 or 15 answered the call. Dowty also have a full-time housing officer, and provide assistance in finding accommodation, including the guarantee of loans, to key employees.

Specialists for which new demands have arisen are of several kinds. Diversification creates fresh needs, and the entry of Newton Chambers and Company into the manufacture of chemical plant led them to establish a practical post-graduate course in chemical engineering acceptable to the Institution of Chemical Engineers. The course has also proved effective in deferring call-up. The General Electric Company, like other companies concerned with nuclear engery, have sought physicists and metallurgists from universities and the UKAEA; the Ford Motor Company have established apprenticeships in metallurgy and chemistry; Dowty have also started training metallurgists and physicists; Albright and Wilson foresee a growing need for maintenance and instrument engineers; and with their increasing activity in the exchange of manufacturing licenses, Glacier Metal are looking for engineers with a knowledge of languages.

Companies appear to be showing a growing interest in clerical and commercial training. Thus Albright and Wilson and Dowty have recently established schemes of commercial apprenticeships, and provide commercial and administrative training for boys, preparing them for membership of the Association of Cost and Works Accountants; successful candidates may become cost estimators or production controllers or eventually perhaps company secretaries. Common or garden secretaries are also trained by Dowty, who hold two-year clerical courses, through which some 35 or 40 girls pass each year. Newton Chambers report that in their own area—Thorncliffe near Sheffield—a business training college offering further education and secretarial instruction was set up to counter the shortage, which has thus been eliminated.

The right man for management is still difficult to find; hence the rise of such organizations as Management Selection Limited, who carry out much of their business by designing advertisements that even the man who isn't consciously looking for a job may read from curiosity. The very top positions, once filled by omniscient tycoons, are increasingly being assumed by professional managers, able to tap other people's knowledge and quick to appreciate a mathematical or statistical analysis. Men of this kind are in such short supply that on at least one occasion a company has been purchased merely to secure its managing director. The central problem of today, so Albright and Wilson believe, is the need to transform specialists, recruited to carry out technical work at the beginning of their careers, into senior managers of broad understanding and interests.

In the Right Place

Although much thought is given to choosing the right man, the job itself is seldom subjected to the same scrutiny. But as Glacier Metal remark: "We don't employ people, we get work done." They define the job in depth, and when they have difficulty in appointing a suitable man, they question whether the job is right.

The nature of a job changes and it is sometimes difficult to recognize its new character; a statistician recruited to answer questions put to him by research workers may find himself taken into council at an earlier and earlier stage in the research program until finally he is suggesting experiments. His responsibility is consequently greater and unless his salary is increased commensurately, it will be impossible to hold him or to find a successor.

Glacier Metal attempt to define a job in terms of discretion (even an operative may have to choose between various positions on a dial and it may be more costly to build adequate discretion into the dial than to secure a discriminating man); and secondly, responsibility (the failure of an information officer to notice an important patent may cost his company

many thousands of pounds yet he is probably not paid in accordance with his scope for doing damage). Job specification is also carried out by High Duty Alloys. Eliminating fuzz from the job lets a man know where he stands and simplifies the integration of different responsibilities.

In confirmation of this trend, Management Selection Limited emphasize that management consultants are being used more and more, not just to find the man for the job, but as advisers to discuss the nature of the job long before the stage is reached for filling it. Too often a firm advertising for a production controller has brought to light a cost accountant.

At the Right Time

Having decided to diversify their products, F. Perkins Limited set up in October, 1957, a new products division. The first new products, a range of three outboard motors, were announced at the end of last year. The general manager of the division worked with a small team, making use of existing departments in the company; and the outboard motor was chosen partly on the grounds of its relationship with traditional Perkins products. The designs are of American origin and Perkins acquired the sole manufacturing and world selling rights, apart from an existing licensing concession in Italy. This choice also avoided any question of competing with Perkins customers. The timing of the project has been carefully worked out and a new company, Perkins Outboard Marine Limited, has been formed to handle the motors.

The only recruit enlisted for the project was a man experienced in outboard motors, and staff will gradually be drawn from the parent works to phase in with expanding output. Any deficiency in the main works will be made up from outside. A further new product will be announced shortly.

Another aspect of timing is the forward planning of staff requirements in a growing company. High Duty Alloys, for example, have discovered from investigations that the proportion of their foremen, supervisers and craftsmen in their late fifties will increase during the next five years; steps are being taken to meet the situation. Like the Ford Motor Company and many other firms, they prefer to promote from within. The recently appointed deputy-chairman of Dowty started as an apprentice. The British United Shoe Machinery Company carry out periodical surveys to make sure there is adequate cover for the most important positions. Glacier look four or five years ahead for a new production manager, who may be taken on to fill some junior post initially. Ford and Glacier have management development policies, foreseeing and plotting the progress of individuals. They ask two questions: where the candidate thinks he's going next and where the company think he's going next. As a result of this policy Glacier hope to have less occasion to look outside the company for their executives in future.

In the longer term, successful recruitment depends upon the creation of a sympathetic climate in the schools. To this end Herbert Morris Limited have introduced a three-day course in engineering for Leicestershire schoolmasters.

MATERIALS CYCLE

THE important factor in setting the pace of industrial expansion, of putting new products on the market, is not so much the discovery of new materials, but rather the rate at which those already in existence can be produced economically and applied to best advantage. The bringing into use of a new material requires the co-operation of at least three different organizations: the raw material producer and the refiner, the manufacturer of the semi-finished product such as an extruded section, and the material user. The success of a material depends ultimately on it being incorporated in a machine or in an installation with advantage; an advantage can usually be measured economically, either in increased profitability of a product, or better performance. The attention of producer and semi-fabricator is therefore focused on stimulating consumer demand.

Conception

Consumers may be broadly classified into two categories—those who are aware of their need for new materials and those who are not. On a different footing there are those who are in a position to know what materials are available and who may even be prepared to undertake materials research themselves, as distinct from those who have to be "sold" new materials; the distinction is drawn because it indicates where the demand for new materials comes from, and creates a basis for understanding why some materials are successful quickly while others are, only far more slowly. It is understandable that those consumers who are held up for want of the material with the correct performance should employ highly developed liaison with their raw material producers and fabricators, the aircraft industry being an example; similarly that those who are content with existing materials should not. The expansion of the market for a material occurs far faster where there is a demand than where it has to be sold; hence the tendency for materials to be used in small amounts for specialized applications long before the wider market is developed. The commercial production of many materials developed and used in the war—polyethylene and nitrile synthetic rubbers, for example—has only become possible in recent years through development of wider markets.

Industry has automatically organized itself into a structure where it can become aware of new materials, with systems for developing them and bringing them into use. The raw material producer is usually equipped for research, and material and process development; he has application engineers, technical salesmen, and is equipped for market re-

search. His aim is to find what is needed, or what could be used, and to make and develop it. The maker of semi-finished goods is there with process and applications engineers in contact with both producer and consumer. Lastly, the user has designers, development engineers, laboratories, and production departments. Liaison for feedback of information and experience must exist, and for this and for economic reasons has emerged the integrated company, incorporating both producers and consumers. Important also are the outside liaison bodies—the federations of producers and users, which especially enable the small user to share his experiences and to save duplication of development effort, as well as to be the meeting ground for making known to the producers requirements for new materials. Behind the co-ordinated producer, semi-fabricator and user are the research organizations, independently or industrially owned, and the universities. In materials their role is an essential one—understanding material structure and behavior, predicting new compositions from theory, and ironing out production and performance difficulties from a fundamental understanding.

Birth

The structure exists for bringing new materials into production and use, but there is an inevitable time interval between the conception and wide-scale application. It is the time of modifying, testing, and developing markets. Market expansion of a material may be very slow, until production units are large and used to capacity. Subsidizing first sales is seldom resorted to, but the return of research overheads may be spread out over an indefinite period.

As an example, the demand for titanium came initially from the aircraft industry who were prepared to pay a high premium for the increased strength to weight ratio. This metal demands three stages in manufacture of wrought products: manufacture of the metal, melting to ingot, and working, say into sheet. The first two stages required development of special equipment, a task undertaken by ICI. In 1957 came the White Paper on Defense, and it became apparent that the continuing progress of the metal would be a fight because of the decreased demand. The company looked to other outlets utilizing other properties, which lead to an extensive drive in the chemical, petroleum and allied industries. Progress was slow because evaluation depended on protracted service trials, but this field promised to offer a market even larger than in aircraft. Production techniques were revolutionized and could have permitted substantial reduction in prices if the new plant had been used to capacity. Despite these difficulties the price of the wrought product has been reduced from £15 per lb. in 1953 to £5 per lb. today. The company's faith is illustrated by the fact that they continue to spend £500,000 a year in research and development.

The history of the launching of titanium illustrates several points which are important in the period between conception and commercial use of a new material. Consumer confidence in a material must be created; confidence which comes from experience in use, and from the time-consuming accumulation of performance data. This confidence is promoted by liaison with the user in the development stages. Problems which the user must face are redesigning to make best use of the properties of a material, and acquisition of labor with new manipulative skills, working perhaps with newly developed equipment. "Technical service" aimed at overcoming these initial difficulties is an important selling point for the producer, and is a major factor in the modern approach to putting materials into use quickly.

Adolescence

An indirect economic factor which is important, especially with wrought products such as sheet, derives from the re-use of scrap. The importance is dependent on the relative costs of raw material and wrought product, but it is true with most new materials that the early years see development of scrap-recovery processes. With titanium large stocks of scrap mounted up until the question was satisfactorily solved. The apparent attractions of mouldable sheets in filled thermosetting resins (reinforced plastics) are offset by the non-usability of the scrap, which once cured can not be softened or remelted.

The question of redesigning an article to make use of a new material presents a problem to the would-be consumer—especially where it involves retooling on production lines. Justifiably, there is a tendency to be cautious before undertaking such a step. An example of this necessary redesign has been the application of plastic foams, which although attractive in weight and rigidity, demand quite different concepts for the frame structure which they may replace, say in aircraft wings and fins.

The consumer/fabricator may or may not be guilty of prejudice against use of a new material but there are examples where this does hold up application. The constructive remedy is for the producer to analyze the prejudice, gain the confidence of the user, and help to overcome it. High impact pvc is making slow but sure progress in the fluid and gas pipe industry, where despite active research into non-corrodible pipes and methods of protection there is still feeling against the use of plastics. The manufacturing company, in this case British Geon, has enlisted the co-operation of the potential users in testing the material, to instill confidence in the use of plastics.

The Butterley Company Limited, makers of a lightweight concrete aggregate called Aglite, have encountered reticence in the building trades, and have combated this and the question of redesign by providing data and help in application.

Maturity

The size of stocks of a material kept by a producer, or engineering consumer, depends on the demand for

the material in the works as well as the rate of deterioration and the market price fluctuations. That supply "ex-stock" is attractive is undoubted; but it is often impracticable. It is enlightening to see just how fast distribution of perishable materials can be, as typified by the movement of radioactive isotopes with short lives. The effect of use of material stock in a market of falling prices can be very upsetting to the material producer, and it was primarily to combat this fluctuation that the metal exchanges were established. It has been noticeable how the users of copper have been working on very low stocks as the direct result of the falling price. A help especially to the manufacturer of semi-finished materials such as extrusions and sheets has been the standardization of sizes. It is intended not only to safeguard the interests of users and producers, but also to clear the air of undue complications, and to rationalize specifications. One of its greatest impacts is on the country's ability to compete in international markets where contracts may be lost by the existence of conflicting standards.

What will help new materials to be put into use quicker? Primarily the desire and willingness of consumers to try them out, which is one result of good liaison with the producer. Rationalization of specifications will undoubtedly continue to help. Why define, for instance, the impact strength, elongation and tensile strength, if it is only the latter which is important?

One danger, perhaps, is to go too fast, leading possibly to the premature rejection of a material. Plastics generally suffered from too rapid progress ten years ago; the aircraft industry in welcoming ptfe tried to use it too quickly and ran into teething troubles derived from the immaturity of the manufacturing processes. That materials can be made commercially available in only a few years after their first conception—epoxides for instance took only three years—is a feature which is bound to continue.

It is more common now for users to be aware of future material developments and to be prepared for them when they become available. A large number of the important engineering materials of the next ten years are already known—poly-propylene and poly-carbonates, tantalum and vanadium, silicon nitrides and borides, for example—but these will all have to pass through the stages of modification, and development of the production processes to an economic size before they can be commercially launched.

The development of quite new materials has undoubtedly stimulated research into "old timers," and many of our natural materials such as timber are being given a new lease of life by being made more consistent in their properties.

In the plastics field, one of the underlying trends has already started—the production of petrochemicals in this country. This step appears to follow from the policy to move the refining and processing to where they are economically best sited. A similar policy is reflected in the trend to produce more highly finished semi-finished goods, thus making use of mass-production techniques such as continuous annealing and surface coating, at the most sensible stage in the producer—semi-fabricator—user chain.

It is a prevalent attitude of materials producers nowadays to offer tailor-made alloys and materials, but this may prove irreconcilable with the policy to make use of mass production.

RESEARCH PROJECT

It has become a commonplace to stress the importance of research and development in modern industry. Warnings come from all quarters—"we must step up our research and development program"—"we are lagging behind our foreign competitors in research." Is it possible that the profusion and intensity of these statements exaggerates the seriousness of the situation? In an age when economies change so rapidly we should be wary of being caught up in a strong current of plausible popular opinion and so swept innocently towards an unforeseen destination. It is possible that under all this pressure, research tends to be carried out for prestige instead of product. Perhaps it will even become fashionable for managements to hire a few backroom boys in the same spirit as they would hire a professional coach for the works soccer team.

If the structure of an industrial organization is to be properly balanced then its attitude to research must be in perspective. The various sections of a firm are interrelated and interdependent and each must be properly planned. So the size and importance of the research and development section must surely be dictated by its relationship with the other sections and the balance of the integrated structure of them all. Why then all this fuss about research and development?

The answer of course is obvious and has already been stated: the demands of research must be looked at in perspective. But the perspective we knew has now changed. In fact our economy has changed from one based primarily on finance, high-speed production and the use of natural resources, to one that is dependent upon a technology derived from the oldest and richest of man's natural resources—his own unlimited ingenuity. Furthermore, these changes have been very much for the good of industry and for the strengthening of free enterprise. They have not lessened the roles of good management, mass production and planned selling; on the contrary they have critically increased them. Yes—this time popular opinion is moving along the right lines. The happy combination of science and business skill has been, and will continue to be, a most fruitful merger. Provided the balance is kept in perspective.

An example of balanced management of research affairs can be seen in the policy and workings of the Metropolitan-Vickers Electrical Company, Limited. Research minded since their conception in 1901, they have maintained a high order of industrial efficiency throughout by the constant application of good man-

agement to the diligent endeavors of a good research department.

Prototypes are designed and constructed within the research department, subjected to extensive tests, and then tried in commercial application before manufacture on a large scale is transferred to the factory. High-vacuum pumping plant, X-ray equipment, electron microscopes, mass spectrometers, and linear accelerators are examples of the specialized equipments that have passed through these stages and are now maufactured on a production basis within the factory.

This development of new products is carried out in close co-operation with their scientific apparatus sales department, which also deals with a limited number of commercial contracts by means of which the market is developed and experience of users' needs obtained, thus enabling further advance in design. This is frequently reinforced by study in the laboratory of known and possible uses to which the new product can be applied, with the object of further broadening the market.

In addition to investigations in the fields of technical knowledge of direct concern to the company, active participation is taken in devising and constructing experimental equipment for fundamental research to be carried out at universities and other research organizations. Among the fruits of their research program have been the discovery of the molecular distillation properties of oils which opened up an entirely new field of vacuum physics and the study and investigation of high-temperature creep of metals. These studies have led to new materials of construction permitting steam and gas turbine plants to operate safely at the increased thermal efficiency that accompanies higher operating temperatures.

Regeneration

Science is continually creating new industries and revolutionizing old ones, through the media of research and development. The effect is like that of a rolling snowball: as research creates a new industry so the new industry creates new problems for research—the ensuing research aids the established industries and eventually creates new ones—and so on. It is in fact a regenerative cycle, energized by man's insatiable desire to improve his standard of living, and the application of his ingenuity to do so.

The basic pattern began to take shape at the time of the industrial revolution. James Watt was initially an independent inventor. But unless he had been fortunate enough to join forces with a man of great organizing skill, Matthew Boulton, his mechanical genius might well have been less fruitful or even of no avail at all. Without the business man who was also an innovator, Watt would not have been such a key figure in the industrial revolution. The Watt-Boulton combination was perhaps the beginning of the snowball. Invention nurtured invention. Watt and Boulton called upon the inventive ironmaster, John Wilkinson, to bore the cylinders for their engine. And so the success of Watt's engine was to some extent the consequence of an invention of Wilkinson's—a machince for the accurate boring of cannon. The circle was completed when Wilkinson bought some of Watt's new steam engines to operate the blast of his foundry furnaces and later to operate his mechanical equipment. Since then the cycle of generation and regeneration has revolved many times, continually widening with the impetus of further research and newer ideas, and their steady ever-increasing application to industry.

Although the present pattern of industrial growth began at the time of the industrial revolution, it was not until the close of the 19th century that it began to crystallize firmly. Thomas Edison, the great inventor, realized fully that the growth of industry was highly dependent upon the new ideas, which until then were still entering industry in a haphazard fashion. Edison set up his own industrial research laboratories and fed his ideas directly into companies either formed by himself (for he was a shrewd business man) or formed as a result of co-operation between him and the well established firms of his time.

Edison by the astute and diligent application of his energies gave considerable impetus to the precipitation of the newly forming regenerative structure of modern industry. But this was only the beginning. To continue to thrive, industry needs the constant application of fresh impetus from within its closed circuit.

In the Small Firm

It is well known that within the realms of industry there are those who exist without making any kind of contribution to the lifeblood of progress. But surely they are doomed to mere existence at the best, and if they have no part to play in the progress of industry and society they may either fade away or be swallowed up by their more enlightened and expanding competitors. This does not mean that there is no place for the small firm. On the contrary, many of these firms have an increasingly important part to play in the new scheme of things, particularly in technical development.

As the rate of production increases and firms become more and more geared to mass production it becomes less convenient and less efficient for them to break down their tooling in order to develop and produce prototypes for future production. The changes that are necessarily involved in the development of a prototype are not suited to the mass-production layout, and unless the firm chooses to run a development shop of its own the development work must be farmed out. Of course many of the larger firms do successfully and efficiently run internal development workshops, but if they are to be highly efficient they must constantly be worked to capacity. This means the parent body must have enough development work on hand to keep a fully equipped development department in constant operation at full swing. But, even more important than capacity work-

ing is the need for stimulus among the personnel.

People engaged in research and development require a constant stimulus to be creative and effective. As Dr. Grey Walter has remarked, a complex organism needs an environment of noise—better random noise than no noise at all—if it is to function. If research workers are starved of interest by too much mundane repetition in their work they become sterile. For this reason the variety of work, which would normally be greater in a development firm than it would in the development section of a producer organization, ensures that the men are stimulated by, and retain a lively interest in, their work.

One example of such a small firm is that of Morfax Limited of Mitcham, Surrey. This company employs some 300 highly skilled men and specializes in the problems of metal working. The way in which this firm has established itself in the one decade of its existence is testimony to its functional value to industry.

Solving metal-working problems, producing prototypes, and keeping up-to-date with their machines and techniques is the sole dedicated purpose of this small firm. They have no standard production line and no standard output, in fact the company's main sales product is the scope and capacity of its men and machines. Many of the prototypes made are of their own design and these are sometimes patented.

During their short history they have given valuable service to many of the giant organizations by using their unique skills and energies to produce prototypes ranging from small jigs and fixtures to huge wind-tunnel components for aircraft testing. The superiority of the speed, range, and quality of their work has been fully recognized by their many patrons and there can be no doubt that they will continue to be of value in their field as long as they maintain their lively team spirit and go on building up a store of knowledge of metal technology by working on the problems of, not one, but many different types of producer firms.

Firms like Morfax are not new; George Wailes and Company Limited, London, were operating on similar lines 100 years ago and are still there today; but their role in industry is new, in fact they now fill a dual role. They greatly assist the larger organizations by carrying out awkward developments and prototype production. But they also cater for the research and development needs of other small firms, who cannot afford to operate such extensive research and development laboratories but who wish to secure their benefits in order to compete with their wealthier expanding rivals.

By Co-operation

Another means by which small and big firms alike can contribute to and derive the benefits from pure and applied research, is through the co-operative research organizations. Co-operative research is a comparatively recent innovation. It is the latest addition to the pattern, brought about by recognition of the need to "nationalize" scientific knowledge in order that it can be carried out on a scale adequate to the problems.

During its forty or so years of existence, the Department of Scientific and Industrial Research has contributed to the evolution of a flexible and efficient organization by which the Government can assist industry in solving its essential problems and step up the regenerative stimulus of new ideas.

There are three main activities—support for scientific research in the universities, to ensure the output of high quality engineers and scientists for industry; the operation of research laboratories working on topics of national importance; and financial support in partnership with industry of co-operative research associations. DSIR's own laboratories are of many different types, including the National Physical Laboratory, the Chemical Research Laboratory, the Road Research Laboratory and the more recent Mechanical Engineering Research Laboratory. While it is impossible to evaluate the economic results of their research, it cannot be doubted that they contribute on a wide basis to the general advancement of knowledge.

Perhaps the most directly useful of the activities of the DSIR is the fostering and subsidizing of co-operative research associations made up of groups of industries with common interests. There are now more than 40 of these research associations with a total membership of about 15,000 firms. The subscriptions required for membership are very modest, being in the case of a small firm much less than the annual salary of an office boy. However in spite of this, the membership is still often limited to the enlightened few. In the case of the Production Engineering Research Association the total membership is still only about 5 per cent of those eligible to join. The broad outline of the work of PERA is: (1) developing new and improved production techniques by practical research; (2) assisting members with specific production problems; (3) supplying members with the latest information on economic production techniques; and (4) securing the most rapid and effective application of better production methods by extensive liaison and training programs.

New concepts of production efficiency are being constantly accepted by the most progressive companies applying the results of PERA's steadily expanding research into production techniques and equipment. In one member company the turnover has been increased by 300 per cent without any increase in floor space or labor, and with negligible capital expenditure. Their current research program includes investigations into such techniques as cold extrusion. By their work in this field PERA have enabled British industry to make up a 25 year time lag from their German rivals.

As research proceeds, previously unsuspected barriers to higher efficiencies are being discovered. Many experienced production engineers do not realize that

present limits of economy, output, and quality in everyday production practice are often set by minute undetected vibrations in machines and tools. A continuous program of research extending over several years is now throwing new light on the nature and effects of these vibrations.

A much simpler example of the practical benefits that may be obtained from organizations such as PERA is the case of the ordinary twist drill. Although twist drills have been in existence for very many years, by application of modern scientific research techniques PERA has shown that quite simple changes to the angle of the point of the drill can result in substantial improvements in the economy of production. Member firms employing the results of this research have reported large savings in tool consumption.

Direct co-operation between member firms and the research associations is often of great benefit to the particular firms involved and thereby to industry generally, through the regenerative process. A recent example was the development by the British Iron and Steel Research Association of an automatic device to control accurately the gauge of metal strip in reversing and tandem mills. The idea for automatic gauge control began when member firms asked BISRA to investigate the possibility of improving existing techniques of keeping a constant tension on the strip being rolled, in order to control the gauge. BISRA replied by suggesting that a much better gauge control might be obtained by varying the applied tension, to maintain constant load and using electronics to obtain a quick response. The idea of using tension to hold the strip gauge constant with a load-meter producing a control signal seemed to be so simple that an experiment was carried out immediately, with encouraging results.

Later the simple theory became elaborated and a practical method of measuring the strip thickness from a direct reading of the load in the mill and the position of the screws which adjust the roll setting was evolved. This instrument, which became known as the gaugemeter, was then developed into a second control method in which the rolls themselves are adjusted by a loadmeter signal to control the gauge.

At this stage the work was still experimental, being carried out by BISRA at the mechanical engineering block of Sheffield University. Some time later the initial development work was finished by BISRA with a demonstration on a 4-stand tandem mill, and this showed that while automatic gauge control principles were sound enough, a good deal more work would be needed before it could become a really practical proposition.

A far sighted decision was then taken by the board of Davy and United Engineering Company Limited, Sheffield (who are members of BISRA) in setting up an instrument division whose task was to bring automatic gauge control to the stage of commercial application. The first step was to set up a complete manufacturing facility with ability to manufacture not only automatic gauge control itself, which by this time had developed from a simple electrical circuit to an advanced analog computer using fast response self-balancing servo-systems for solving the various control equations, but to manufacture also the loadmeters, tensionmeters, loadcells, and other ancillary equipment. After lengthy practical trials the system graduated from a development project to a marketable product and was placed in the hands of the Davy and United selling organization.

One of the first models to be installed was at the Dominion Foundry and Steel Company, Canada, and its success led to licensing both Canadian Westinghouse and Canadian General Electric Company to manufacture on the North American continent.

Thus, in less than ten years automatic gauge control has advanced from a casual suggestion to a widely applied piece of control engineering, through the close co-operation of a research association and a few of its member companies. Further development work is now being carried out as a joint effort between United States Steel Corporation, General Electric Company (USA) and Davy and United to apply the principles of automatic gauge control to a hot rolling mill.

Through the Big Firm

Although there are over 40 research associations in Great Britain, the major part (90 per cent) of the nation's industrial research, measured in terms of expenditure, is still carried out by privately owned industrial laboratories, and forms the backbone of British industrial research and development.

Much of the credit for Britain's leading position in world industry today is due to firms that originally established their supremacy a hundred or so years ago, and have maintained the pioneering spirit throughout. One of many such examples is that of Babcock and Wilcox, Limited. This company has always had a pioneering outlook and has been responsible for many of the most important developments in steam-raising practice. For example it produced the forged steel header which made high-pressure boilers a practical proposition, introduced the Bailey water-wall, developed pulverized-fuel firing and was the first with the fusion-welding of high-pressure boiler drums, and the Cyclone furnace.

The company attaches much importance to research and development as well as to routine testing and quality control of materials and products. In its modern research station at Renfrew, the research and development department employs a personnel of well over 300 skilled men and technologists. The most modern and extensive equipment is installed for chemical and physical analysis, mechanical testing, metallurgical examination, and the application of electronics to engineering. Research is carried out into problems associated with design, manufacture and operation of combustion and steam generating equipment.

The development of Babcock steam-raising plant is, in fact, a continuous process, soundly based on the company's world-wide experience of plant performance and on unceasing research and development revealing new materials and techniques. Such factors have kept Babcock and Wilcox continually ahead in the field of steam engineering.

From Abroad

British firms cannot always be first with new ideas. Many vital industrial developments come from overseas and it is of considerable importance for British firms to be quick on the uptake when such developments occur. By being quick to make use of valuable foreign inventions and developments we greatly minimize the chances of being left behind by foreign competition.

A recent example of foresight of this kind is the case of the free-piston gasifier. This device which underwent nearly all of its development in France is now being manufactured under license in Great Britain. The free-piston gasifier, which may be considered as a supercharged diesel engine, acts as a generator for power gas which is then utilized in a gas turbine. The opposed pistons in the engine cylinder are directly attached to the larger pistons which operate in single acting cylinders. These act as compressor cylinders on their inner side and deliver the supercharged air to the engine cylinder. The end spaces of the larger cylinders constitute cushion cylinders, in which the air is compressed on the outward stroke and provides the energy for the return stroke. The pistons have no connecting rods and no crankshafts, being kept in phase by a light linkage which does not transmit driving power. Since the moving masses are opposed and perfectly balanced there is complete freedom from vibration. The abolition of connecting rods and crankshaft gives a unit of much less weight and smaller dimensions than the conventional diesel engine of the same output, and cumbersome engine structures and foundations are eliminated.

There can be little doubt that this important new technique will have a large role to play in turbine engineering in the very near future. It is due largely to the foresight of a handful of enterprising British firms that it is now in production in Great Britain and it does them great credit that they were able to gear up for the production of this foreign development so rapidly. For example, the National Gas and Oil Engine Company Limited, Ashton-under-Lyne, were able to produce their first all-British gasifier only nine months after receiving their manufacturing license.

On Thin Ice

Although, by and large, technical developments progress along a logical and somewhat predictable course there is always the risk of a radical new technical development arising to eclipse an existing one. Such events can be disastrous to the firms that have based themselves entirely upon the older technology. Even the most prophetic cannot often foretell the arrival of a completely revolutionary invention.

For this reason it is most important that firms which are geared closely to a narrow field of engineering should keep a watchful eye upon current research and at the same time endeavor to expand their work into other fields which fall within the range of their technical skills. A practical example of this philosophy may be seen in the aircraft propeller industry. In the early post-war years, the advent of the jet engine caused a number of radical changes in the aircraft industries and in particular cast considerable doubt upon the future of the conventionally propelled aircraft. At this time de Havilland Propellers Limited, who had already adopted the policy of expansion into allied fields, stepped up this expansion by making the fullest possible use of the many technological skills involved in the design, development, and production of aircraft propellers. Although the propeller business actually remained secure, it did no harm at all for de Havilland's to expand their technical interests in this way; on the contrary, they are now flourishing in the propeller industry as well as several others; for instance they now produce 90 per cent of the electrical generators for guided missiles made in Great Britain.

The New Barrier

From these examples the regenerative pattern of research and development is apparent. It may be expected to assume increasing importance in the future, unless the balance between the component parts of the productive process becomes disturbed. Thus before the introduction of automatic computers we were approaching what might be called the data barrier; perhaps we are now nearing the research report barrier where results and discoveries become too numerous to be handled or used effectively. Attempts to take advantage of such abundant information may in fact clog the productive process. To counter such a weakness, industry will require to carry out not only scientific and technical research, but research into the mechanism of research itself and the part it plays in the manufacturing activity as a whole. Research will be increasingly applied to subjects and areas of industry where its use had never hitherto been contemplated. The spread of operational research is a beginning.

DESIGN DATA

How an idea for a new or improved design comes into being, and the process by which it is translated into the working specifications and drawings, are traced in this report. Reference is made to a variety of industries large and small—an industrial heating service, control instrumentation engineers, compres-

sor manufacturers, domestic electrical appliance makers, the motor industry, and aircraft construction.

Where it Starts

The design of a new or improved industrial product may be triggered off in various ways. It may be the outcome of months of intensive investigation by sales and market research staff; most domestic consumer goods, for example, originate in this way. On the other hand, a new idea may be "handed on a plate" to the designers by a prospective customer, or may arise from work already in hand by a process of natural induction; or it may be prompted by the availability of new materials and techniques. In all these ways, there is a powerful element of cross fertilization; successful design is almost certainly never the result of seeking inspiration in the seclusion of an ivory tower.

An example of customer-inspired development is offered by Isopad Limited, a small firm specializing in the design and supply of a new form of heating service—electrical surface heaters for vessels ranging from laboratory crucibles to 1,000 gallon processing tanks; for tracing pipelines; for de-icing aircraft propellers and engine air intakes; and for a growing variety of engineering and chemical and nuclear power plant applications. Most of the company's work today is directed to special purpose and one-off jobs, and involves a very large element of consultative and advisory service to the customer; yet when the company started in 1946, their sole object was the manufacture of high-grade domestic electric blankets. It was the chemical industry who realized that the principle involved could be applied to their needs, and thus initiated a "chain reaction" of technical development.

Developments in marine echo sounders have sometimes been inspired by ideas put forward by the fishing industry, Kelvin and Huges Limited report; but fundamental improvements in operational and design techniques generally arise from experiments conducted by the firm's research team. This team is permanently employed on the development of echo sounders and sounding techniques, and has its own research vessel, *Lalla Rookh II,* commissioned in 1956 for practical work at sea.

The inductive process is exemplified by the phototransistor direct-reading displacement meter for vibration analysis recently put on the market by Fairey Air Surveys Limited. What inspired an air survey company to enter into this unexpected field of instrumentation was the fact that the company's research department, in carrying out a development contract for airborne camera mountings, discovered that there was no apparatus on the market suitable for measuring the low frequencies in which they were interested; and so they evolved their own instruments which, it is believed, are the first to measure oscillatory displacements directly, and subsequently they decided to exploit an untapped market.

Market research led Broom and Wade Limited to develop their recent range of portable oil-flooded rotary compressors. In 1952 their Canadian organization reported that American oil-flooded rotaries were threatening to drive the reciprocating compressor off the market. Surveys of the new American machines showed that they had the advantage over piston machines in a number of ways: smaller size and weight, lower freight charges, higher operating speeds, lower initial cost, easier maintenance resulting from the smaller number of working parts and the absence of valves, and cooler air. From the outset, however, it appeared clear to Broom and Wade that they could improve on the American designs, which were of the two-stage in-line type. For access to the low-pressure blades, therefore, the high-pressure rotor assembly had to be removed. By adopting a geared side-by-side two-stage arrangement, it would be possible to give complete accessibility to both sets of blades; and moreover the unit would be more compact. It was therefore decided to go ahead with the construction of a 120 cu. ft. per minute prototype on these lines—and success in the field trials of the early machines led to the present range of compressors from 120 up to 630 cu. ft. per minute—and a development potential which is far from exhausted.

A design development that was initiated by a combination of market research and the availability of new techniques is represented by the Transmatic electronic controller for air conditioning systems introduced recently by Teddington Industrial Equipment Limited, to supersede their earlier electromechanical controller. Again, study of the American scene, where conditioned air is a "must" in all public and most private buildings, showed a growing preference for the electronic controller which has a quicker response, and is more sensitive and more compact than the electromechanical device. The American controllers were, however, based on thermionic valves; and Teddington decided that they could produce a more rugged and still more compact instrument—and eventually a cheaper instrument—by using transistors and printed circuits. Moreover, transistors and printed circuits are "news": it is not only in consumer goods that the designer needs to have a sense of the contemporary. Scientists and engineers are almost as susceptible to fashions in techniques as a young woman is to the latest creations of Yves St. Laurent.

How it Continues

The first step in designing a successful product is to determine exactly what the customer needs. From the outset, then, there must be a close liaison between the sales department, after-sales service and the designer. In the case of special-purpose designs to customers' orders, direct contact between user and designer is usually essential, because what the customer asks for in the first place is quite often not what he really wants! In the case of electrical surface heaters, for example, Isopad have found frequently, on investigation, that the degree of control precision

demanded by the customer is unrealistically stringent and would involve him in needless expense.

Generally speaking, the design process—the development of the original idea into the manufacturing specification and detail drawings for the guidance of the workshops—follows the traditional pattern: establishing the basic design, calling for experimental work, the extent of which varies with the "newness" and the size of the project; estimating the manufacturing costs; building and proving the prototypes or the pilot model in the experimental, or research and development department; and analysis of the prototype design from the manufacturing view point with a view to simplifying the production process, standardizing dimensions, tolerances, quality, and using interchangable components so far as is possible without detriment to the performance.

The preparation of drawings, specifications, parts and materials lists, follows and, when complete and approved, they are released to the production departments. The main developments noticeable today in this process are an earlier and much closer liaison between the design and production departments; increasing attention to the international aspects of standards, essential for those hoping for overseas markets; in complex projects, the extensive use of electronic computers for "optimizing" the design parameters: and a growing use of "3 D" models and full-scale mock-ups to supplement drawings of complicated buildings, particularly those involving a multiplicity of pipeline and cable runs, such as aircraft, locomotives or chemical processing plants.

In Control Instrumentation

Now looking at the design process as applied by a few individual firms: in designing the Transmatic air conditioning controller referred to earlier, Teddington Industrial Equipment Limited decided to build up from standard modular units. In the first place this was conceived mainly with the idea of eliminating "on-site" maintenance by the use of self-contained units, but it has valuable repercussions on production and on stock holdings, as a wide variety of controllers —some 20 or more—can be made from four or five basic units.

As in most efficient engineering organizations, Teddington's design and development sections—both quite small—are under the direction of the same engineering chief executive. The basic ideas and preliminary cost estimates of the Transmatic having been settled by the design section, the development engineers worked out the scheme on a "bread board" and the sales staff were brought in to discuss styling and to indicate the sales potential of the instrument. A trial "production" run was then carried out in the development laboratory, some dozen sample controllers being built up, tested thoroughly, and submitted to the production shops for method studies, together with the detail drawings and instructions produced by the design office. At this stage, the publicity department came into the picture and was "fed" by the design engineers with material on which the publicity campaigns and technical literature were based.

The first 50 controllers produced by the shops were sent back to the development laboratory for thorough performance testing, and other samples were submitted for field trials. This procedure soon revealed desirable modifications, which are being built into subsequent production runs: for instance, the original specification, based on American practice, overlooked the fact that in the United Kingdom rather cruder and simpler methods of temperature control in heating installations are employed than is customary in the United States. Fortunately it was a comparatively simple matter to incorporate a control element to regulate the heat supply temperature in accordance with the outside air temperature—the usual British procedure.

In Compressor Manufacture

In the case of Broom and Wade's rotary oil-flooded compressor mentioned earlier, although prototypes in 120, 250 and 600 cu. ft. per min. capacities were successfully run both in the United Kingdom and Canada during 1953, there remained many design problems to be solved before they were fit for the open market. In the earliest machines, the low-pressure rotors were run at the same speed, and from the outset it was obvious that this was not an efficient arrangement since it resulted in a lower blade tip speed for the high-pressure rotor than for the low-pressure rotor. This was easily overcome by using a suitable step-up gearing between the rotors, but it still remained to determine what was the most economical blade tip speed; this would determine the stator bore sizes and maximum engine speeds.

Other factors which had to be decided were the choice of blade material with the necessary wear qualities and dimensional stability under conditions of temperature and in the presence of oil, and the weight of the blades, which would influence the range of operating speeds; the ratio of rotor diameter to length, which affects the control of leakage over the tips of the blades and at the ends of the rotors; determination of the minimum oil flow, rotor and blade clearances, coupled with the maximum volumetric efficiency; and an effective and economical filtering system had to be devised for removing the oil from the oil-saturated air delivered from the high-pressure outlet.

All these problems were solved in some two years of joint effort by the design team and the research and development department. Once the basic ideas were crystallized, representatives from the production side—planners, cost accountants, foundrymen, machine tool operators, the lot—were called in to the first of a series of "production method" meetings to make suggestions. At such meetings the design is finalized and authorization is given for the acquisition of special-purpose machinery and equipment.

Early in 1956, the first batch of 120 cu. ft. per minute compressors were under way. A number of these early machines were submitted for field trials by prospective customers; any improvements suggested by the results of such field trials, as well as those suggested by the production side, as a result of manufacturing experience at the regular production method meetings, would be worked up by the design office as "mods" for incorporation in the next production batch.

Although effective liaison between the production and design sides is established by the production method meetings, still closer day-to-day co-operation is the aim of Broom and Wade's general manager.

In Domestic Appliances

Domestic electrical appliances made under the aegis of the General Electric Company, Limited are produced in several factories, which "sub-contract" their design work to a single central service, the "Appliance Design Center," at Wembley. Here are gathered together all those responsible for the generation of new ideas and their translation into production possibilities: departments concerned with costs and information, technical design, mechanical design, appearance design and planning production.

In the technical design department are a number of engineers and physicists, each specializing in a group of related products—those involving the conversion of electrical energy to heat energy, those involving the use of refrigeration, or those involving motors and moving parts, for example.

Each specialist has available laboratory or workshop space in which he can conduct his own experiments and tests. The mechanical design department, which specializes in the mechanical design of products, comprises an engineering drawing office and a prototype workshop. The engineering drawing office produces sketches or drawings for prototypes, and can also produce finished working drawings for the manufacture of the final article, depending on the extent to which the factory concerned desires this to be done. The department is also responsible for keeping the center up to date on new materials and finishes.

In consumer goods such as domestic electrical appliances, appearance is an important selling factor, and is taken care of by the appearance design department, manned by skilled industrial designers who work in the closest possible day-to-day association with the staff concerned with all the other functions.

The planning engineer section maintains the essential liaison between the Appliance Design Center and the different factories producing the various articles. This section advises other members of the center staff on tooling and the best utilization of existing plant. Where necessary, it prepares factory layouts involving the use of new plant or the re-siting of existing plant, and prepares estimates for tooling, plant and machinery.

The way in which a new appliance is born is as follows: preliminary cost comparisons being favorable to the new idea, a meeting is held of all Appliance Design Center personnel likely to be involved, together with the sales department concerned, and the works who will make the appliance. The object is to prepare a brief to which the center may work. The Appliance Design Center then proceeds in two stages, "A" and "B." In the "A" stage the technical designers develop any new ideas necessary. Models constructed at this stage are only to try out new schemes and bear no resemblance whatever to the final article.

At the "B" stage the technical designers, with the collaboration of the mechanical drawing office and the workshop, construct working prototypes as complete as possible in the technical sense. In parallel with these working prototypes, the appearance designers, again with the co-operation of the workshop, design and make appearance prototypes; which resemble exactly the final product in shape and in finish.

At the conclusion of the "B" stage, final agreement is reached with the works concerned regarding the whole design. The "B" stage appearance prototype is then submitted by the Appliance Design Center on behalf of the works to the sales department for approval. After any modifications have been approved the center can hand the whole job over to the works concerned so that it can be tooled up for manufacture.

In The Motor Industry

Let us now consider the large-scale and highly competitive automobile industry, as typified by Vauxhall Motors Limited. Here, development is primarily inspired by the persistent demand of the mass car-buying public for progress—functional and impressiveness of appearance. Every new model involves vast capital expenditure on specialized plant and machinery, and costs are based on a four to five year production run, with perhaps two minor "face-lifts" during the intervening period, to introduce some new feature or to eliminate some point of sales resistance.

Design and development must go forward on a very short time scale; and to make this possible, the design and development teams—which are numbered in hundreds and which work in parallel under the same senior engineer—are broken down into highly specialized sections. In the preparation of a new design, these teams are preceded by two other groups directly responsible to the chief engineer—the "forward product study group" and the all-important "styling group."

The forward product study group are continuously working on new technical possibilities. When sales trends indicate to the management that the time has come to launch a new venture, the forward study group "crystallize" the basic ideas around which the new automobile is to be created, and feed the principal dimension and layout data to the styling group.

Styling is a fundamental part of the design process of a modern motor car, and at Vauxhall full-scale three-dimensional models are built to develop the external lines and appearance. In the earlier stages,

the model is worked out in clay. When satisfied with the lines, a permanent glass fibre appearance prototype is built, representative of what the final vehicle will look like from outside. To complement the appearance prototype a wooden mock-up known as a "trim buck" is built to develop the interior styling and finish and to establish the position and arrangement of seating, controls, instruments, accessories and so on.

The glass fibre prototype is used not only as an aesthetic standard, and as a starting point on which the advertising and publicity departments plan their campaign, but also for preparing body work formers used in producing the hand-built prototype bodies of the vehicles and assisting in laying down the full-scale loft plates by the engineering design team for production. Body lines having been settled, the engineering design sections, in close liaison with the production planners, go into action. As regards standardization, Vauxhall Motors conform to a comprehensive system of standards governing minor items such as attaching or fixing parts, established by their American parent company, General Motors Corporation.

The building of prototype parts and components follows closely upon the completion of drawings and every detail of the car must be hand-produced for design checking and development prior to its release to the production planners, and prior to the heavy expenditure on its production tooling. Not only are power units bench tested, but functional components ranging from window winders to complete gearboxes are shop tested on special rigs in a similar manner.

Prototype cars are tested both on the road in the United Kingdom and overseas, and on Vauxhall's new proving ground near Luton. This proving ground provides facilities for accelerated life testing on special surface tracks, Belgian Pave and other media, in addition to braking and handling testing on a banked high-speed circuit; 1,000 miles on special surface tracks is equal to 100,000 miles of normal road use.

Any defects in the design shown up by the treatment of prototype cars and components are corrected and re-tested, and when engineers reach confidence in their design the working drawings are released to the production planners. In contrast to those products made on a batch basis, any small improvements arising from field experience or from bright ideas, serving to eliminate unnecessary cost, can be introduced on the production line at any time.

In Aircraft Construction

An interesting example of the results of close integration of design and production is the Argosy freighter-coach aircraft made by Sir W. G. Armstrong Whitworth (Aircraft) Limited, conceived less than 2½ years before its maiden flight this January. In this aircraft, design was viewed from the production standpoint from the outset, and preliminary production planning began with the initial design study. From the production viewpoint, the more the aircraft could be broken down into sub-assembles, the shorter the manufacturing cycle time; but from the performance viewpoint, this could result in weight penalties because additional joints would be required in the structure.

Getting together early, in the form of a high level development committee representing the principal design, development, and production sections, enabled these two viewpoints to be thrashed out, as well as ideas on processes and methods. For instance, the design side wished to use the Redux metal-to-metal bonding process on the Argosy for reinforcement in areas of high stress level; this process needs special plant and a build-up of experience before it can be applied as a production routine and it was therefore important to make an early decision on its introduction.

Liaison between design and production is fostered at all levels, informally as well as by formal committees. There is day-to-day contact between production planning engineers and the design office; and the latter are kept fully up-to-date on new equipment in the shops by means of a plant manual.

Aircraft construction, incidentally, is one branch of engineering in which the practice of hand-building the prototype in the experimental shop is dying out, because the time lag involved is too great. Today the first two or three complete aircraft off the production line serve usually as the prototypes for flight development, preceded by the first production fuselage which is used for the static strength tests. Although this may involve some modification in tooling and so on, this does not involve the same penalty that it would in the automobile industry, because aircraft tooling and jigging is generally more versatile.

Owing to the complexity of the job and the ease with which bottlenecks can be created, very careful programming and phasing of the design, development and production stages is called for—priority being given to the full-scale mock-up for laying out the interior, control runs, "plumbing," etc.; wind tunnel tests and mechanical tests on detail parts; and design of the main structural parts, that is fuselage and wings, so that the production side can tool-up as early as possible.

Extensive ground-rig development on fuel systems, hydraulics, air conditioning, engine installation, and so on, is carried out before such systems are installed in the aircraft, and static strength tests, stiffness and resonance tests are usually completed before the first aircraft flies. Fatigue tests on major structural assemblies will probably be taking place concurrently with prototype flight tests.

Towards Integration

In the aircraft and missile industries, and in other highly advanced fields, such as nuclear power reactor construction, there is beginning to be apparent a reversal of the policy of breaking down the design into specialist sections. The specialist engineers are there—they must be—but their efforts are directed jointly towards the design of a complete entity rather

than an assembly of components and systems. The Atomic Energy Division of the General Electric Company, Limited, citing the design of a nuclear power station, says that "there is rarely found in any other field of technology a situation in which mechanical, electrical, civil and chemical engineers are so interdependent. Even a comparatively slight change in one detail of the basic design frequently necessitates a re-appraisal of many other features . . ."

Summarizing, therefore, the trend of the design process today is towards earlier and closer integration of every aspect of the project—getting together with the customer to find out exactly what he wants and, having determined this, bringing together representatives from every department involved in the making, selling and servicing of the product to decide how the customer's needs can most efficiently and economically be satisfied.

PRODUCTION PLANNING

CHANGES in production methods have been far-reaching and no limit is in sight. Automation is an accomplished fact and is spreading, but it can only be applied to large-quantity production. A revolutionary change is the introduction of means for controlling and programming machines singly or in small groups, to produce any number of products from one off, and capable of being re-programmed cheaply and quickly at any time. Computer control of production is in use and developing. In spite of mechanization, staff are still needed—and likely to remain so.

Nowhere in engineering has revolutionary development been more marked in recent years than in the production departments. Today, the production engineer has at his disposal not only the traditional types of plant, themselves generally improved in numerous ways; he also has available many new machines, processes and materials.

Automatic control

There is, of course, nothing new about automatic manufacture; mechanization is very old indeed, but it is the extension of the process towards full automation which is important, together with its application, hitherto impracticable, to small as well as large quantity production, or even to "one-off" work.

Mechanized production has its limitations based on output quantity and range. Equipment and tooling are costly, and only large outputs can justify the capital expenditure involved, both initially and when a change of product is made. Nevertheless, large fully automatic production lines are used extensively, the motor car industry providing a familiar example of their justification on both practical and economic grounds. Mechanization is the natural basis for the more recent development of full automation, in which product inspection is carried out automatically and, by means of a feed-back of information to the producing units, corrective action is taken, also automatically, as required. This is true automation, as distinct from mechanization with which, because of the hold gained on the popular imagination by the word automation, it is often confused.

It is a well known fact that a large part of the British engineering industries is organized in small and medium sized units, many of which are not likely, if only for financial reasons, to install fully automatic production lines. Moreover, many engineering products are not required in quantities which would be suitable for mass-production methods; ships' engines, to quote only one of many obvious examples, are usually made on a strictly one or two-off basis. In these small and medium quantity production fields further changes are taking place, for the very developments which have made full automation possible—electronics in particular—have also made it practicable to apply automatic control to small quantity or even one-off production.

Punched card or tape, or magnetic tape control of what is virtually a standard machine tool enables complicated machining to be carried out by semi-skilled labor, without the need for expensive jigs or fixtures. It permits the process to be operated once or repeated indefinitely with the same degree of accuracy, and the master tapes or cards can be stored for re-use at any time. Preparation of the masters is inexpensive, and although the capital equipment needed for control purposes is relatively costly, it enables the machine to be used with complete flexibility to produce automatically anything within its capacity, to have its program changed at any time quickly and cheaply, and to revert to manual control if required.

Planning Production

A production department must base its output on actual or estimated orders, and it must produce articles of the specified quality and cost; it has therefore to carry out its planning in close co-operation with the sales and other commercial departments. In addition, due consideration has to be given to the question of using new and improved methods where applicable, to the introduction of completely new products, and to the modification of existing products as a result of service experience or customer suggestions. Consequently, the research and development, design and service departments of the business have also to be consulted when production plans are being made or modified.

Before a product can be put into production, the question of prototype manufacture may arise, and this cannot as a rule be done by the production department. Frequently, the product in question will be made, by hand methods, in the experimental department, or in the toolroom, but there are occasions when a fairly large pre-production run is necessary. In such a case the product may be made in quantity in a small but fully equipped separate department maintained specially for the purpose.

Quasi-Arc Limited, for example, in the manufacture of manual and automatic arc welding electrodes, make use of a pilot plant under laboratory control for pre-production runs of any length before a newly-developed product is passed to the normal manufacturing department. Typical work for the laboratory production machinery was the making of quantities of electrodes used for extensive impact testing when the company's recently introduced "Ferron No. 3" electrode, specially designed for nuclear energy work, was being developed.

Proper co-operation between the production engineer and the other departments concerned is fundamental to successful production planning; many problems are involved, and they can only be solved if each department sees the difficulties facing the others. In putting their "Hoovermatic" domestic washing machine into production, for example, Hoover Limited allowed for 100 per cent electrical and mechanical testing, which had to be done in the cycle time of the lines as a whole, and fitted the new line into the shop at their Merthyr Tydfil factory without interfering with other production work. This involved designing special-purpose equipment on an extensive scale, and was achieved by a team consisting of designers, development department personnel and operating staff from Merthyr.

Getting the Information

Successful control of production depends on much more than correct design and layout of machines and equipment. Conditions are not static; there are changes in many aspects of the subject from time to time, and those responsible for control of production must have a great deal of information on which to base their decisions. In this field the electronic computer is developing as a valuable management tool.

Such a computer has been installed in the Hollerith Works at Letchworth (now International Computers and Tabulators Limited) for day to day control of production. Four outstanding advantages are claimed for this installation, the first of its kind in the United Kingdom: it gives complete flexibility, as the effect of changes in demand, labor or materials can be measured at once; a daily stock record is available and over and under stocking are eliminated; the production program is fully integrated, and because everything is ready at the right moment, production time can be a realistic minimum; the effects of alternate courses of action are worked out at extremely high speed to provide a basis for decisions. All these things have had to be done before, of course, the significant factor being that the machine now does them at vastly greater speeds than could ever be achieved manually.

Production Staff

However much work may be done in the future by machines, staff will still be needed to plan the work of production, for in spite of the popular conception, machines cannot think, they can only do what they are told, and the work of ensuring that the best use is made of machines of all kinds calls today for specialist staff. How this staff itself is organized, and how large it is, must depend upon the size of the firm concerned, and the complexity or otherwise of its products.

At the Witton Engineering Works of the General Electric Company Limited, there are really six factories, and the products range from large turbo-alternators which are made on an individual customer-requirement basis, to such items as hair-dryer motors and small silicon rectifiers which are produced in large quantities. Transformers and switchgear of all sizes and degrees of complexity are also produced at the Witton works.

All new production problems and all major replanning to suit changed products are the responsibility of the central production engineering department. Separate sections within this department deal with particular aspects of Witton production, the section leaders being men of specialist experience; production foremen, for example, have been transferred to lead some sections. In addition to this group of production specialists, there is a methods research section which has responsibility for developing new processes and, of course, for keeping abreast of developments generally, so that advantage can be taken of any new ideas. Between them the various sections of the department are responsible for designing plant, materials handling equipment and—an item which is sometimes overlooked in production planning—materials stores. Product designs may be modified if desirable by agreement with the product design department concerned. Finally, there is a section of the department devoted to value analysis, which investigates, at the request of the factory management, all aspects of a particular product—its design, production methods, purchased parts, assembly—and, in co-operation with production, design and sales departments, reports and recommends changes if desirable.

A different, though no less complicated problem of production organization has to be dealt with by Accles and Pollock Limited, who make and manipulate tubes, mainly ferrous but including non-ferrous of many specifications, to high precision limits. Their production requirements vary from very large quantities down to one-off orders. Most of the production is to customers' specifications, and most new products are developed to meet a customer's particular need, but some are introduced according to an estimate of market requirements. A new product may be only a simple variant of an existing one, and as such it can probably go straight to the production department. On the other hand, it may need considerable development before it is suitable for production, in which case it is passed to the experimental and development department. This is strictly speaking a non-production unit, but it works in close co-operation with the production shops. Orders for a single product or for a small number may, in fact, be

made in the experimental department, as the main production facilities of the works may not be suitable for them.

All the staff of the experimental department have had extensive experience in production departments before being appointed to their present posts, and they are given further training on selection. Accles and Pollock use a simple method for keeping the two sections of the works in balance. Several of the development engineers have working with them on a part-time basis a retired former production worker of long experience and of supervisory status. This experiment, tried by Accles and Pollock as a means of finding useful work for active retired employees, has been beneficial to both parties. The younger man, who has a good technical training, has not had the time to gain the practical experience of the older man, who, in his turn, may not have the technical qualifications of his partner, and each has something to give the other. On this basis what might seem to be a potentially explosive combination has worked to the satisfaction of all concerned.

A summary of space research effort to date indicates that a total of eleven earth satellites have been placed in orbit and three successful space probes have been launched. Of the eleven satellites, six are still in orbit. Two of the three space probes passed near the moon and are presumed to be in a solar orbit. In addition to these successful launchings, the United States has conducted eleven unsuccessful attempts to launch satellites or space probes. No information is available on unsuccessful Russian attempts. The following tabulation gives the chronology of successful launchings.

SATELLITES

VEHICLE	LAUNCH DATE	APPROX. LIFE	NATIONALITY
SPUTNIK I	4 Oct., 1957	3 mos.	USSR
SPUTNIK II	3 Nov., 1957	6 mos.	USSR
EXPLORER I	31 Jan., 1958	3-5 yrs.	USA
VANGUARD I	17 Mar., 1958	2,000 yrs.	USA
EXPLORER II	26 Mar., 1958	3 mos.	USA
SPUTNIK III	15 May, 1958	19 mos.	USSR
EXPLORER IV	26 July, 1958	14 mos.	USA
PROJECT SCORE	18 Dec., 1958	13 mos.	USA
VANGUARD II	17 Feb., 1959	200 yrs.	USA
DISCOVERER I	28 Feb. 1959	12 days	USA
DISCOVERER II	13 Apr., 1959	1 mo.	USA

SPACE PROBES

VEHICLE	LAUNCH DATE	RESULT	NATIONALITY
PIONEER III	6 Dec., 1958	68,000 mi. alt.	USA
LUNIK	2 Jan., 1959	solar orbit	USSR
PIONEER IV	3 Mar., 1959	solar orbit	USA

—from ENGINEERING
May, 1959

COMMANDER R. L. BROOKS, USN

IMPROVING UNDERSTANDING BY GUIDING THE SELECTION OF THESIS SUBJECTS

THE AUTHOR

is an Engineering Duty Officer who has served 7 years in the United States Fleet, 4 years in shipyards and 5 years in research and technical work at the David Taylor Model Basin and the Bureau of Ships. He is presently Senior Assistant to the Supervisor of Shipbuilding and Naval Inspector of Ordnance, Camden, New Jersey.

EDITOR'S NOTE: *The author did not accept any compensation for this article.*

INTRODUCTION

Two problems which have been much discussed in recent fears are the shortage of well qualified engineers in this country, and the weaknesses in our system of educating students for engineering and scientific fields. If we may assume that these discussions have demonstrated that there is such an engineering shortage and that the education system does have weaknesses, then it would appear that suggestions are needed which give promise of improvement for either or both of these problems.

One such suggestion is presented below. Briefly, it involves setting up of close working relationships, in order to improve the selection and execution of thesis subjects, between research activities and universities. If properly handled, such relationships could result in direct benefits of considerable importance to each research activity and to the students, while side benefits would also accrue year by year to the universities. At the same time, mutual understanding would be cultivated and a broader community of interests would grow up among the students, the professional personnel of the research activities, and those representing the universities.

NEED FOR IMPROVEMENT IN EDUCATION

Launching of the first Russian satellite was quickly followed by a public outcry against the many alleged defects in our educational system. While the primary target of this emotional reaction was the secondary school and its partial failure to give our youngsters a proper background and motivation toward the sciences; critical attention has also been directed at other parts of our educational system. This attention was to some extent only a continuation of earlier discussions of the need for improvement in our schools. As one example of such discussions, in June 1956 (reference 1), the Engineers Joint Council pointed out the need for professors to state clearly the employment conditions that students may expect as professional engineers, in order that the movement toward unionization of engineers might be counteracted. This movement was believed to result from a failure to recognize adequately the needs, responsibilities, and contributions of professional employees. The Council also emphasized that colleges must develop in engineering students an understanding of professional concepts by demonstrating the application of these concepts to the solution of actual engineering problems. A need to expand opportunities

for engineering educators to become better acquainted with the total environment in which engineers must work was also stressed. For this purpose, the Council recommended temporary employment of educators in nonacademic fields, and the utilization of employers with "professional vision" in classrooms and in student seminars. Such action would enable students to appraise more realistically their status following graduation.

It has been estimated that 80 per cent of all engineers are employees rather than private practitioners, which is not the case with other professional people such as most doctors and lawyers. Engineers in their every day problems are often concerned more with getting things done by people than with working out textbook type solutions, a fact sometimes overlooked by engineering colleges.

From such ideas, one could conclude that engineering schools ought to teach their students more than is now being taught about the day to day operation of engineering organizations, and the problems of working with and through other people. Otherwise, the student may not learn during his college days how to evaluate information that can only be generated progressively or how to reason in harmony with others from incomplete data to produce necessary day-to-day decisions. If these concepts were carried out by more engineering schools, graduates would be able to enter upon their active professional careers with a better understanding of exactly what an engineer is and does.

Various steps have already been taken, principally by school authorities, to improve the students' understanding of engineering in actual practice. One such step is the cooperative plan, following the pattern of vocational schools, in which students spend fixed terms working as engineers with industrial companies. Also, many engineering professors carry out research investigations for industry in a consultant capacity. In several cases, fully developed research organizations have grown up alongside the parent educational institution.

The serious weaknesses which still exist, even though improvements have been made, caused Dr. Griswold of Yale University to state: "Unfortunately most of us get no further . . . than damning the schools and waiting for Washington to do something about them." (reference 2).

A SUGGESTION FOR IMPROVING THE HANDLING OF THESIS SUBJECTS

The proposal presented here involves the following elements:

a. An outline of suggested thesis subjects would be prepared about once a year by each research activity which desires to participate in such an endeavor.

b. Such outlines would be worked up by program managers and would, for each subject, give a brief description of the work needing to be carried out, indicate its importance in a current or projected field, show its relation to key reference material, indicate equipment and calculating machines that will be needed, and give the name of the engineer at the research activity who would be available for advice and coordination.

c. These outlines would be furnished to several colleges which offer degrees in appropriate fields and which desire to receive such assistance.

d. Thesis supervisors at the colleges would use the latest outlines in assisting students to select a subject which most nearly satisfies the individual student's needs. Supervisors would continue to exercise direct authority in determining adequacy of the subjects chosen and quality of results achieved, in relation to the required academic standards.

e. Each student would then carry out his work of thesis preparation, experimentation and write-up.

f. In order to assure that the thesis work helps to satisfy the needs of the research program from which the subject was selected, periodic reports should be submitted to the program manager, and his guidance requested. This can best be accomplished by personal visits of the student where possible.

This system would satisfy the requirement given by Captain Chadwick in reference 3, that a thesis should provide practice to the student in combining study with creative endeavor to demonstrate the natural interchange between education and design in advanced areas inhibited by outstanding teachers.

BENEFITS THAT COULD RESULT

For each thesis that is carried out under this system, substantial benefits could be gained by the student, by the thesis adviser, and by the manager of the research program. But, probably the most important result is the improvement in understanding which should come from the closer contacts.

The student who carries out a thesis selected in this manner, gains the confidence that he is working on a subject of worthwhile value and of current importance; he gains a direct and welcome access to personalities and organizations actively engaged in research work; he gains a feeling of contributing a necessary part to the overall team effort; and he gains the chance to seek employment at this same research activity after completing his college work. Possibly his most important benefit is the opportunity to observe actual working conditions as they exist in practice, and thus be able to make a better choice when he takes a job and begins his engineering career.

Thesis advisers at the college gain a better conception of current status of developments; they gain a more direct partnership position in building for a better future; and they gain a self assurance that they are helping the flow of ideas which will break down the barriers that tend to grow up between the academic and the workaday worlds. In addition the

relationship between instructors and students should improve. In reference 4, General Hershey discussed the difficulty of maintaining the propriety of these relationships in the face of the recruiting attractions being offered by industry.

Those who manage research programs can assign top priority to subjects which need resolution but are held up by a shortage of engineers. Such subjects are usually very plentiful, especially at the level of difficulty appropriate to bachelors' and masters' degrees. The research activity gains in man hours of student effort proportional to its zeal in developing such a thesis program; it gains improved understanding and public relations, and what could be most important, it gains personal contacts which should lead to the recruiting of some of the students to take jobs in its active organization. In addition after having observed the students' abilities while carrying out the theses, the research activity will be better able to choose the best persons to fill its vacant positions.

Responsibility for producing results in each program from which subjects would be selected under such a procedure, rests with the research activity. For this reason, the initiative in developing a thesis system as proposed above should also come from the research activity. Potential benefits which could be gained seem to be a real inducements for such initiative by progressive research organizations.

REFERENCES

1. Professional Standards and Employment Conditions, report of Engineers Joint Council, reprinted on pages 809-813 in November 1956 JOURNAL of American Society of Naval Engineers.
2. Education and Engineering by Vice Admiral E. W. Mills, U. S. Navy, Retired, pages 187-190 of May 1958 JOURNAL of American Society of Naval Engineers.
3. The Education of Naval Engineers by Captain Guy Chadwick, U. S. Navy, Retired, pages 35-48 of February 1952 JOURNAL of American Society of Naval Engineers.
4. Specialized Manpower by Lt. Gen. L. B. Hershey, U. S. Army, pages 409-411 of May 1957 JOURNAL of American Society of Naval Engineers.

Investigating the mechanism of collapse of cavitation bubbles on a ship's propeller, Dr. A. T. Elllis, of the California Institute of Technology has developed a camera which can make 1,000,000 exposures per second. The light from the subject is polarized and then passed through a Kerr cell, which has the ability to rotate the plane of polarization of the light when acted on by an electric voltage. The rotation of this plane determines whether the light will be passed further through a polarized filter, or blocked at this point. The voltage, determining the "shutter" speed, is pulsed by a radar-type vacuum tube. Since it is impractical for a film strip to move at a fast enough rate to record the images successively, the film is held stationary and a mirror attached to the rotor of a small air turbine rotates 100,000 times a minute and reflects the image sequentially to make a movie of the bubble collapse. The photographs have indicated that shock waves with accompanying pressures of several hundred thousand pounds per square inch are generated by the bubble collapse.

—from SCIENCE NEWS LETTER
March 28, 1959

Two Dutch submarines now under construction have an unusual hull arrangement. The pressure-resisting portion of the hull is formed of three cylinders arranged on nearly equilaterial centers, with one on top of the other two. The twin lower cylinders contain the propulsion equipment. The upper hull contains the ship control spaces and living quarters. The three hulls, forming the "hard" structure, are surrounded by an outer, non-pressure hull which serves to provide the desired external form. It is believed that the pressure hulls, each of considerably less diameter than a conventional hull, will permit operations at greater depth.

—from SHIPBUILDING AND SHIPPING RECORD, February, 1959

DONALD L. HERR

BASIC REQUIREMENTS OF PRESSURE TRANSDUCERS IN PRECISION MACH NUMBER AND PRESSURE-RATIO COMPUTERS

THE AUTHOR

A quite complete biography may be found on page 595 of the JOURNAL *for November 1958. He is an Honorary and Naval Member of the Society, and has had several articles published in the* JOURNAL *including the paper for which he was made an Honorary Member.*

He served on active duty in the Navy from December 1940 until January 1946, being promoted from Ensign to Lieutenant Commander, U.S.N.R. He is presently a Consulting Engineer and President, owner and licenser of Mark Instrument Co., Santa Monica, Calif.

He is a member of many technical Societies and in his 43 years has won many honors and wide recognition for his technical achievements. He is an author and inventor of note.

SUMMARY

THIS is a brief report on the basic requirements of pressure transducers, specifically with respect to their equivalent "pressure transmission errors," their effect upon the accuracy of Mach Number and pressure-ratio computations, their effect upon the design requirements of the computers in which they are employed, and the absolute performance requirements of such transducers. By separating out the irreducible intrinsic errors arising from the transducers (pressure-force, pressure-voltage, etc.), the proper design emphasis in the computer itself is delineated. Finally, useful practical and theoretical characteristics are included.

INTRODUCTION

The "Aircraft Instrumentation Nomograph," Figure 1, is a convenient description of the various relationships with which this paper is basically concerned. It is to be noted that static pressure, p_s, is the ambient pressure of the standard free atmosphere at a corresponding N.A.C.A. "standard altitude." Further, it is clear that the ratio of "ram-pressure," p_t, to this "static pressure," directly defines "Mach Number," Mach Number being the ratio of vehicle speed to the speed-of-sound at the ambient standard pressure altitude. Mach Number is, hence, a pure number, *not* a speed in miles per hour or knots. Finally, it is noted that the "differential pressure," q_c, equal to the difference between "head-on boom pressure" or "ram pressure," p_t, and "static pressure," p_s, defines an "indicated air-speed," IAS, in miles per hour or knots, with respect to the air-mass conditions. To obtain "true air-speed," TAS, it is necessary to take into account *both* the ratio, p_t/p_s or q_c/p_s, *and* the actual air free-stream absolute temperature, T, since (the square of "true air-speed") equals the product of (the square of the Mach Number) times (the absolute temperature in

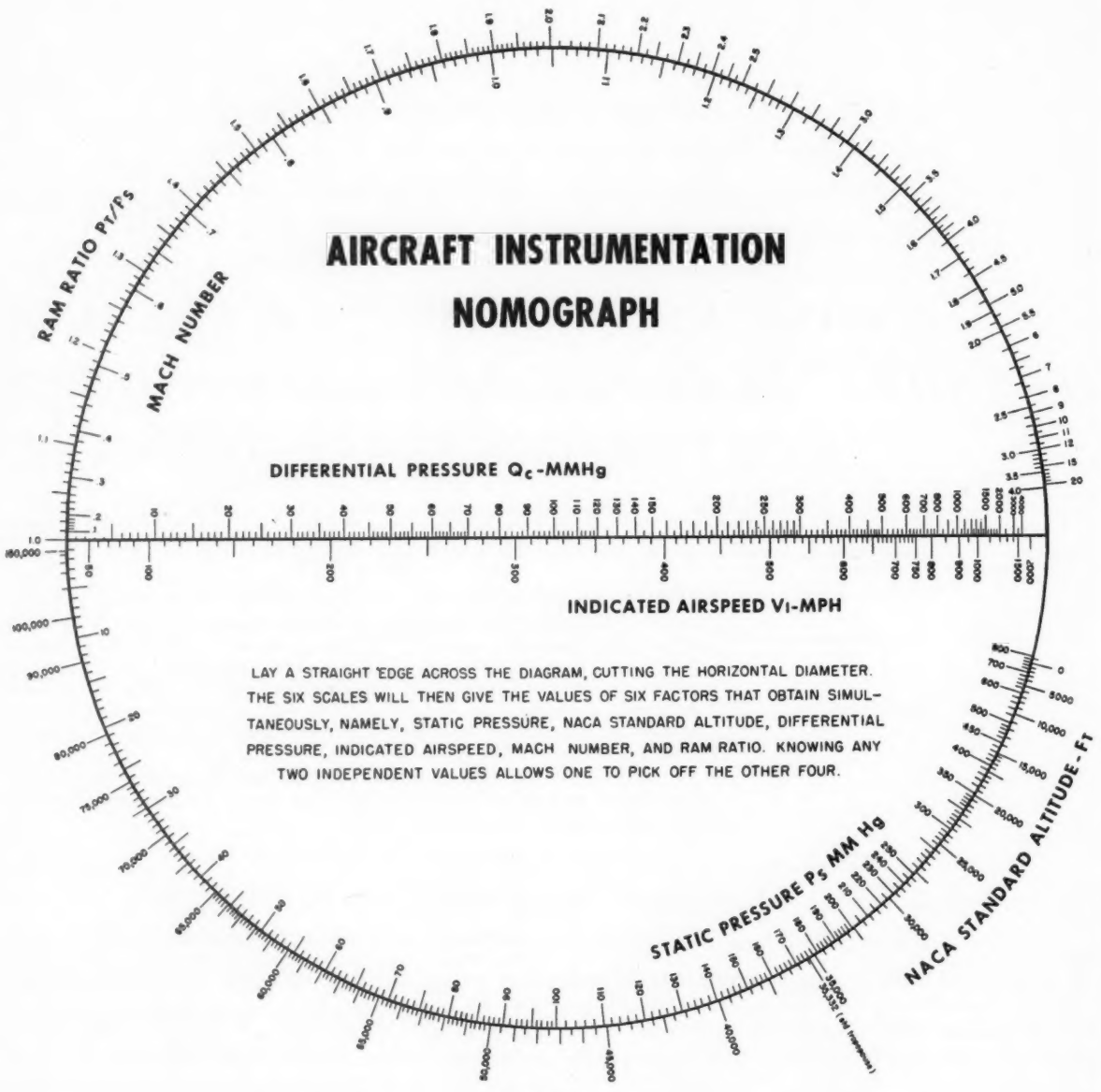

AIRCRAFT INSTRUMENTATION
NOMOGRAPH
RAM RATIO Pt/Ps
MACH NUMBER
DIFFERENTIAL PRESSURE Qc-MMHg
INDICATED AIRSPEED Vi-MPH
LAY A STRAIGHT EDGE ACROSS THE DIAGRAM, CUTTING THE HORIZONTAL DIAMETER. THE SIX SCALES WILL THEN GIVE THE VALUES OF SIX FACTORS THAT OBTAIN SIMULTANEOUSLY, NAMELY, STATIC PRESSURE, NACA STANDARD ALTITUDE, DIFFERENTIAL PRESSURE, INDICATED AIRSPEED, MACH NUMBER, AND RAM RATIO. KNOWING ANY TWO INDEPENDENT VALUES ALLOWS ONE TO PICK OFF THE OTHER FOUR.
STATIC PRESSURE Ps MM Hg
NACA STANDARD ALTITUDE-Ft

Figure 1

degrees Kelvin of the free-air-stream) times (a constant, derived from the adiabatic gas law). In customary air-vehicle instrumentation, p_t and p_s are obtained by critical pitot boom orifices, and T is obtained by a skilfully designed and located temperature probe. In other uses, concerning fuel-consumption and engine optimization or control, the pressure-ratio, p_t/p_s, itself, is the parameter of adjustment and measurement.

In considering the question of accuracy of Mach Number and pressure-ratio computers within prescribed altitude-Mach or other corresponding contours, it is convenient and helpful to first consider the computing mechanism perfect and the pressure transducers imperfect, and then, the computing mechanism imperfect and the pressure transducers perfect. This paper addresses itself to the first consideration to elicit basic performance requirements of such transducers.

Make the following customary definitions:

$$X \equiv \tan\Theta \equiv \frac{q_c}{p_s} \equiv \frac{p_t - p_s}{p_s} \equiv \frac{p_t}{p_s} - 1 \equiv \text{pressure ratio} \quad (1)$$

where p_t is total ram (or inlet stage) pressure, p_s is static (or outlet stage) pressure, and q_c is differential pressure. Then, by the N.A.C.A. formulation for Mach Number

$$(1+X) = \begin{cases} (1+0.2M^2)^{3.5}, & M \leqq 1 \quad (2a) \\ \dfrac{166.92\,M^7}{(7M^2-1)^{2.5}}, & M \geqq 1 \quad (2b) \end{cases}$$

In terms of the pressure transducer errors, $\triangle q_c$ and $\triangle p_s$, alone, there result the following errors in Mach Number, arc tan pressure-ratio, and pressure-ratio, respectively:

$$\triangle M = \left(\frac{1}{p_s}\right)\left(\frac{dM}{dX}\right)(\triangle q_c - \triangle p_s \tan\Theta) \quad (3)$$

$$\triangle\Theta = \left(\frac{1}{p_s}\right)(\cos^2\Theta)\,(\triangle q_c - \triangle p_s \tan\Theta) \quad (4)$$

$$\triangle\left(\frac{q_c}{p_s}\right) = \left(\frac{1}{p_s}\right)(\triangle q_c - \triangle p_s \tan\Theta) \quad (5)$$

The common last factor in parentheses in each of the above expressions (3), (4) and (5), $(\triangle q_c - \triangle p_s \tan\Theta)$ is labelled "instrinsic error" of the function error computation.

RESULTS

The first result of the foregoing is that the maximum possible intrinsic error, and hence, the maximum function error, is given by assuming $\triangle q_c$ and $\triangle p_s$ of opposite sign and of magnitude $\triangle P$ equal to

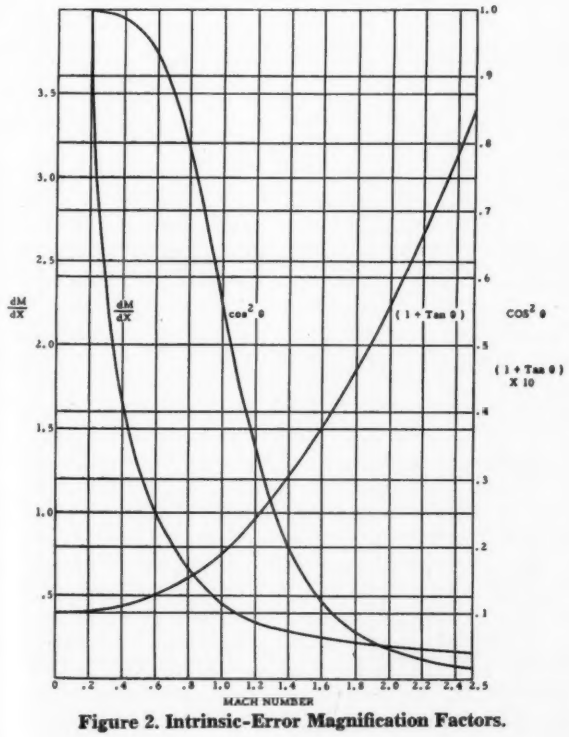


Figure 2. Intrinsic-Error Magnification Factors.

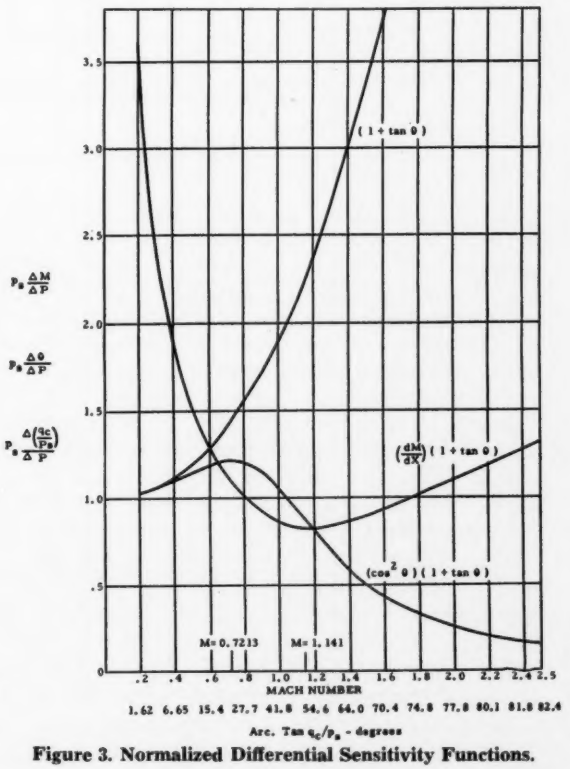


Figure 3. Normalized Differential Sensitivity Functions.

that of the larger of the two, for which:

$$\triangle M = \left(\frac{1}{p_s}\right)\left(\frac{dM}{dX}\right)(1+\tan\Theta)\ \triangle P \qquad (6)$$

$$\triangle \Theta = \left(\frac{1}{p_s}\right)(\cos^2\Theta)\ (1+\tan\Theta)\ \triangle P \qquad (7)$$

$$\triangle\left(\frac{q_c}{p_s}\right) = \left(\frac{1}{p_s}\right)(1+\tan\Theta)\triangle P \qquad (8)$$

$\triangle P$ is called the equivalent pressure-transmission error of the transducers. In Figure 2 is depicted the behavior of (dM/dX), $(\cos^2\Theta)$ and $(1+\tan\Theta)$ versus Mach Number or corresponding pressure-ratio.

By re-arrangement of Equations (6), (7), and (8), there results the sensitivities, normalized to $(1/p_s)$, depicted in Figure 3, viz:

$$p_s\frac{\triangle M}{\triangle P} = \left(\frac{dM}{dX}\right)(1+\tan\Theta) \qquad (9)$$

$$p_s\frac{\triangle \Theta}{\triangle P} = (\cos^2\Theta)\ (1+\tan\Theta) \qquad (10)$$

$$p_s\frac{\triangle\left(\frac{q_c}{p_s}\right)}{\triangle P} = (1+\tan\Theta) \qquad (11)$$

It is readily apparent that the Mach Number error sensitivity in $\triangle P$ has a minimum at $M=1.141$. The arc tan pressure-ratio error sensitivity in $\triangle P$ has a maximum at 22°.5. The pressure-ratio error sensitivity in $\triangle P$ increases beyond bound with pressure-ratio, from its starting value of unity at zero pressure-ratio. Very notable is the fact that low Mach Number computations up to $M=1.141$ place severest limitations on the permitted $\triangle P$ pressure-transmission error of pressure transducers in this application. The next Figures 4, 5, and 6 demonstrate numerically how severe.

In Figure 4, the maximum permitted per-unit $\triangle P$, for a constant maximum error in Mach Number, $\triangle M=0.01$, is depicted for $0.2 \leqq M \leqq 2.5$. By "per-unit" is meant "per unit p_s." For example, for $\triangle M=0.01$ at $p_s=14.7$ psi and $M=0.8$, the actual $\triangle P$, pressure-transmission error, permitted in the pressure trans-

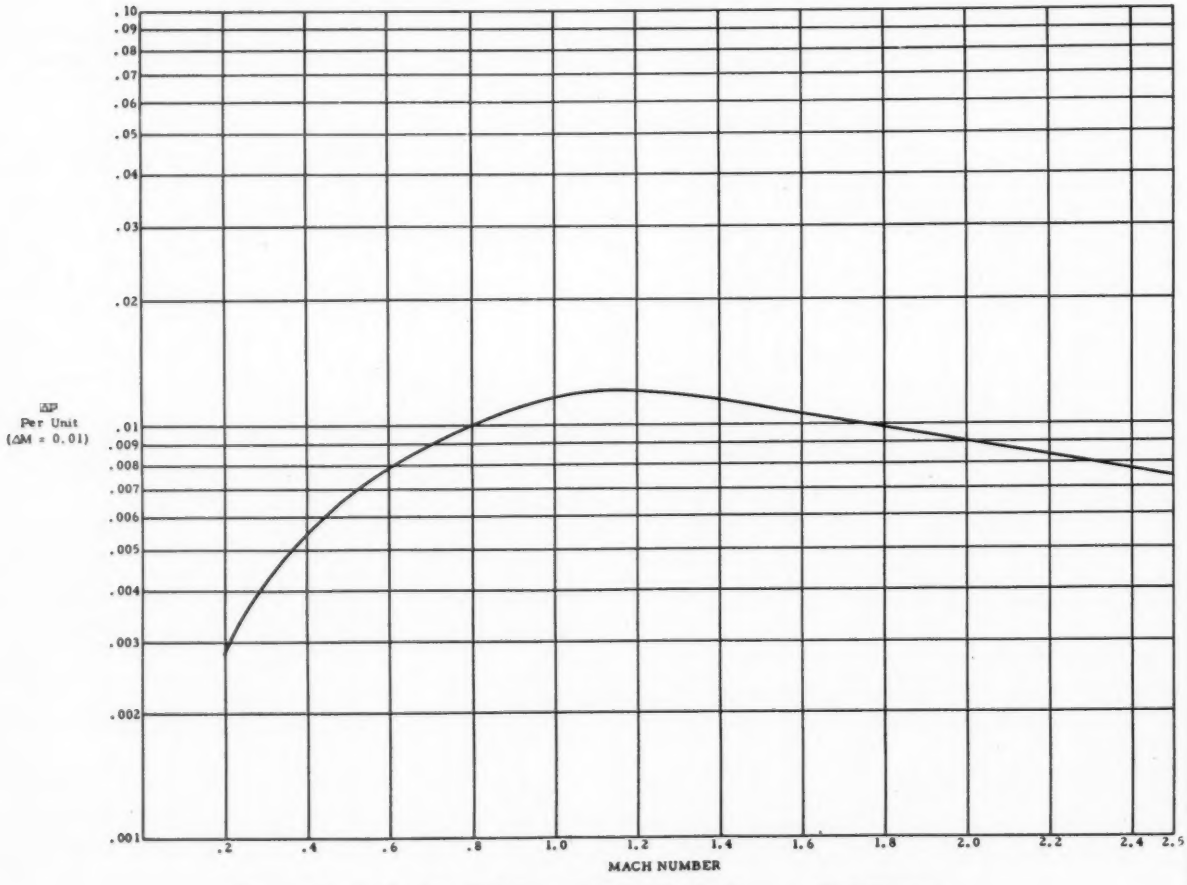


Figure 4. Normalized Per Unit Pressure-Transmission Error vs. Mach Number.

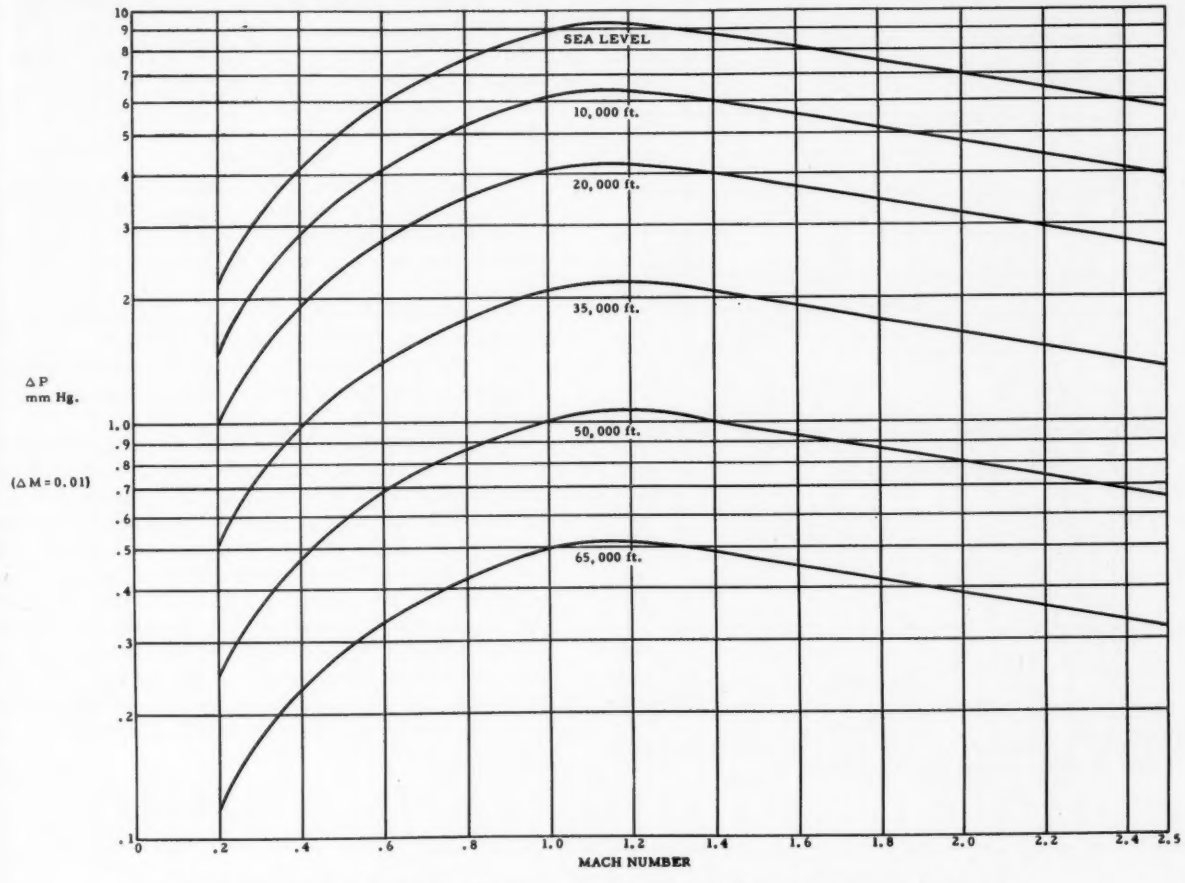


Figure 5. Contours of Constant Altitude vs. Mach Number and Pressure-Transmission Error.

ducers is 14.7x0.01=0.147 psi. If this same $\triangle M=0.01$ were desired down to M=0.2 at the same $p_s=14.7$ psi, a permitted transducer $\triangle P$ of only 0.0028x14.7= 0.0412 psi is permitted. In a third example, the requirement is that, at $p_s=100$ mm Hg, for $0.6 \leqq M \leqq 2.5$, $\triangle M$ should not exceed 0.02. What is the maximum permitted pressure-transmission error, $\triangle P$, of the transducers in the Mach computer, assuming the computer otherwise perfect? From Figure 4, $\triangle P=$ (100 mm Hg)x(2)x(0.0074)=1.48 mm Hg, a very stringent transducer requirement.

Figure 5 presents in yet a different form, for $\triangle M=$ 0.01 and for $0.2 \leqq M \leqq 2.5$, the maximum permitted transducer pressure-transmission error, $\triangle P$, in mm Hg, over contours of constant altitude. It is noted that for all such contours the least $\triangle P$ requirement (maximum $\triangle P$ permitted) occurs for the same M= 1.141; at all Mach numbers lower than M=1.141, the $\triangle P$ requirement becomes rapidly more stringent; at all Mach Numbers greater than M=1.141, the $\triangle P$ requirement becomes gradually more stringent. With increasing altitude, at any Mach number, the $\triangle P$ requirement rapidly worsens. By plotting on Figure 5 the required Mach-altitude contour in a given application, the controlling $\triangle P$ transducer requirement may be immediately determined. For multiples or submultiples of $\triangle M=0.01$ as a Mach tolerance, the corresponding $\triangle P$ in mm Hg is obtained by multiplying the $\triangle P$ from Figure 5 by that same multiple or sub-multiple.

In Figure 6, for $\triangle M=0.01$, contours of constant $\triangle P$ in mm Hg are shown depicted versus altitude and Mach-Number. For example, in a perfect Mach computer mechanism utilizing pressure transducers with a maximum pressure-transmission error of 2 mm Hg, Mach Number can be computed to within $\triangle M=0.01$ for altitudes up to 36,500 feet, but at this altitude, only for Mach numbers in the close vicinity of M=1.141. For the same transducers, at M=2.5, maximum altitude cannot exceed 25,000 feet for $\triangle M$ not to exceed 0.01. The contours in Figure 6 are to be interpreted as those Mach-altitude contours within which the $\triangle M=0.01$ tolerance is not violated

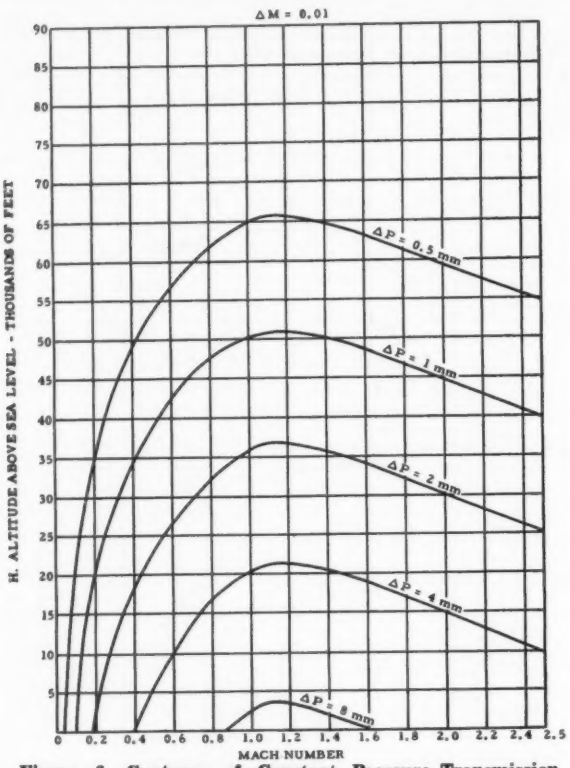


Figure 6. Contours of Constant Pressure-Transmission Error vs. Mach Number and Altitude.

when pressure transducers having the specified △P are employed.

Finally, for reference, Figure 7 depicts certain useful functions of Mach Number, pressure-ratio and arc tan pressure-ratio for error analysis and computer and component design.

CONCLUSIONS

Mach Number computer design to a prescribed accuracy of Mach Number computation employing transducers of specified △P attribute, is at least as difficult for the sub-sonic as for the super-sonic range.

Pressure-ratio computer design should emphasize the maximum pressure-ratio requirements.

Arc tan pressure-ratio computer design should emphasize the requirements in the pressure-ratio range zero to unity.

The pressure transducers used in such computers should have not only identical linear pressure-force, pressure-voltage, etc., transfer characteristics over the required working ranges, but the two transducer outputs should not deviate from one another, for the same input, over the whole working pressure range, by more than the required △P, maximum permitted pressure-transmission error, for the application. Required △P contours for Mach Number computations have been given. Similar △P contours for pressure-ratio and arc tan pressure-ratio computations can be computed from the given error equations for design use.

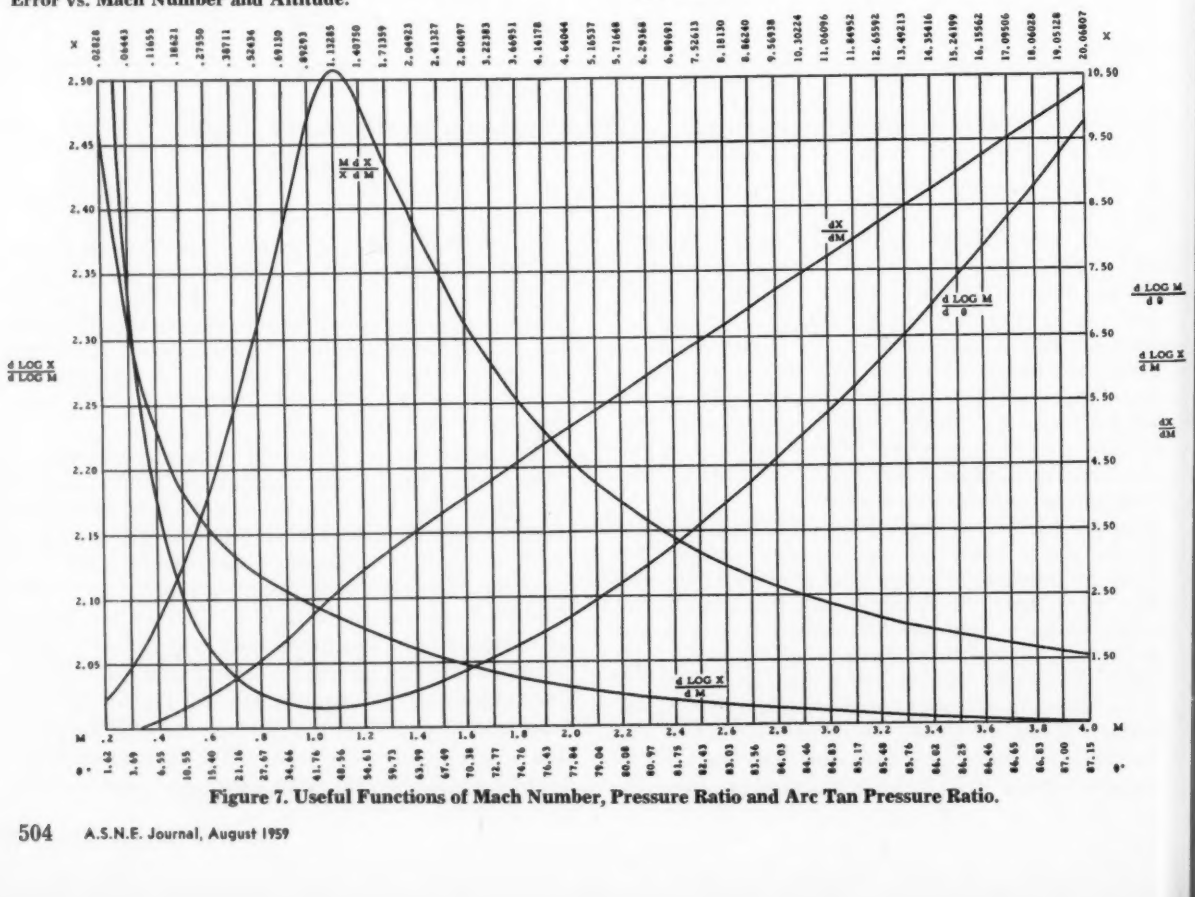


Figure 7. Useful Functions of Mach Number, Pressure Ratio and Arc Tan Pressure Ratio.

"APPLIED MECHANICS REVIEWS"

HYDRODYNAMIC LUBRICATION AND ITS IMPLICATION FOR JOURNAL BEARING DESIGN

ACKNOWLEDGEMENT

F. T. Barwell, Electric Traction Engineer (Research), British Transport Commission (formerly Head of Lubrication and Wear Division, Mechanical Engineering Research Laboratory, Glasgow), is the author of this article. It appeared in the March 1959 edition of "Applied Mechanics Reviews."

INTRODUCTION

THE theory of hydrodynamic lubrication first formulated by Reynolds in 1886 [65] continues to excite the interest of both theoreticians and experimentalists. There are two reasons for this continued interest. One arises from the complexity of the theoretical problems associated with operation of an actual bearing and the second from mechanical engineering developments, particularly the requirement for operation at high linear speeds which has led to a demand for greater precision in design. Reynolds' work had been preceded by the experimental discovery of hydrodynamic lubrication by Beauchamp Tower in 1885 [85] and further confirmation was soon available as represented by the work of Michell.[50] However, experimental investigation of the subject has been hampered by the inevitably imperfect nature of the components used in the tests. Departures from circularity, variations in surface finish, distortion of the bearing due to thermal expansion or elastic deformation and the variation of viscosity of the lubricant with temperature as it passes through the bearing, limit the reproducibility of experiments and the accuracy of generalization based thereon.

BOUNDARY CONDITIONS

Although representing a major advance, Sommerfeld's work[72] had somewhat unfortunate results. He assumed a bearing to be of infinite breadth and that the fluid was able to withstand negative pressures equally as well as positive pressures. The latter assumption presupposed a continuum surrounding the shaft completely, which cannot be relied upon to occur in practice. This led to the prediction that, in the case of a bearing which surrounded the shaft completely, the locus of the shaft center would comprise a straight line situated at 90° to the line of application of the load. Experimental measurements on the behavior of real bearings failed to support this prediction and the locus actually observed could generally be most simply described as a semi-circle joining the center of the bearing with the point of intersection of the line of loading with a circle drawn to represent the radial clearance. This led, for a time, to an unfortunate estrangement between the theoretical and the experimental investigators in this field. However, it has recently been shown experimentally by Floberg [26] that, if a bearing was so provided with seals at its edges as to restrict all move-

ment of lubricant in an axial direction and if the external mean pressure was raised sufficiently above atmospheric, the locus predicted by Sommerfeld was obtained.

The main obstacle to the application of Reynolds' theory to practical design, and one of the major drawbacks of Sommerfeld's approach, has been the difficulty of solving the equations in a three-dimensional form. An early solution of the problem by Kingsbury [45] was to employ the electrolytic tank analogy and indeed design procedures were worked out wherein relationships were derived from two-dimensional solutions and then modified by factors derived from the electrolytic tank analogy.[81,5] Numerical methods of solution have been used many times [66,40,9] and, with the advent of modern electric computers, the complete range of equations has been worked out and published by a number of workers.[77,59,57,62] However, there remain many problems arising from the initial assumptions. In the first instance, the integration of the pressure curve to derive load-carrying capacity must be carried out between the appropriate limits—Reynolds suggested that these were defined by $P = 0$ at the inlet and that $P = 0$ and $\frac{dp}{dx} = 0$ governed the outlet conditions. There is an indication from experimental work that the position where pressure begins to increase may well be determined by the quantity of oil supplied to the bearing. [91,29] Moreover, there is evidence [22,41] that negative pressures exist. These pressures are themselves of necessity of small magnitude compared with the positive pressures in a well-loaded bearing but their existence throws doubt on the $\frac{dp}{dx} = 0$ limit. Sedney et al [67] have suggested that $P = K\frac{dp}{dx}$ at the outlet. Cole and Hughes [16] constructed a bearing of glass and observed the actual position taken up by the film by causing it to fluoresce under the action of ultraviolet light. They showed that the point at which a continuous film disintegrated into fibrils was considerably later than that usually assumed in theoretical treatments. This does not of course provide direct evidence of the extent of the pressurized region of the film but does throw further doubt on the validity of the $\frac{dp}{dx} = 0$ criterion.

Similarly, in theoretical friction studies it is usually assumed that the film is continuous. This results in an over-estimation of the magnitude of frictional loss.

LIMITATIONS OF REYNOLDS' THEORY

Other assumptions made by Reynolds may not be justified under extreme circumstances as follows:

1. that viscosity may be assumed to be constant throughout the pressure area;
2. that the inertia terms may be neglected;
3. that the fluid is incompressible;
4. that the fluid is Newtonian;
5. that any motion of the fluid in a direction normal to the surfaces will be restricted as compared with its motion parallel thereto, and that there will be no transverse pressure gradient.

Evidence exists that neglect of the inertia terms, while it may be important in extreme cases, is unlikely to affect design procedures of bearings for normal use.[57,82,70,6,25,89,42] As with inertia terms, the variation of viscosity with pressure is unlikely to be important in normally loaded bearings, although it has undoubted significance in situations such as gear flanks and ball bearings where intense loads are carried between hardened surfaces.[78,52,44,47,35]

The main difficulty arises, however, from variation of viscosity with temperature. It is clear that, in any bearing, the temperature of the lubricant will be increased as it is sheared and this, by consequent alteration in viscosity, will affect the pressure distribution, friction and load carried. In the case of unloaded or concentric bearings, Hagg [31] made an analysis to allow for the variation in viscosity and consequent velocity across the film. A particularly important conclusion was that, as speed was raised, the friction torque did not increase proportionately as would be expected from iso-viscous theory but, in certain favorable circumstances, may reach a maximum and may even fall off as speed is further increased. This was strikingly confirmed experimentally by Muskat and Morgan.[51]

Variation of velocity across the profile must also result in the generation of pressure. Cameron [10] and Zienkiewicz [93] have elucidated this. However, this factor is not particularly important for design.

THERMAL CONSIDERATIONS

The extension of Hagg's work to loaded bearings operating at considerable eccentricity is rendered difficult by variations in film thickness and therefore in rate of shear around the periphery,[60] and the experimental observations available in the literature cannot be correlated in any simple manner, [48,15] If the assumption is made that, in a running bearing, the majority of the heat is transferred by forced convection in the lubricant rather than by conduction through the bearing housing, it is possible to calculate by numerical methods the distribution of pressure, friction drag, etc., within the bearing. This was first done by Christopherson.[14] He showed that the results obtained for load-carrying capacity were equivalent to those obtained with a hypothetical lubricant having a constant viscosity equal to that of the oil in question at a temperature selected on the assumption that the temperature rise of the oil leaving the sides of the bearing averaged one half of the

total rise. The solution with the viscosity averaged on this basis gave an almost identical value for load-carrying capacity and temperature rise as that derived when the viscosity of the oil was treated as a variable. Friction torque was some 14 per cent high when viscosity was averaged. The energy equation has also been studied by Charnes, Osterle and Saibel.[12] Unfortunately, it has been recently shown experimentally [16] that the adiabatic assumption by no means represents the facts and that a considerable portion of the heat generated is conducted away through the shaft and housing. Moreover, the maximum temperature occurs at or near the point of minimum film thickness. Most theoretical treatments have assumed that, owing to the lubricant still being in a state of intense shear in the diverging portion of the bearing, the temperature would continue to rise. It has also been pointed out [13] that even though in many machines the shaft itself is not situated in a position where it can readily dispose of its heat, it may act as a regenerator in so far as it receives heat when passing through the pressure film which it gives up in passing through the unpressurized region. This leads to a greater uniformity of temperature throughout the oil film than would have been predicted from the adiabatic theory. Wilcock[92] suggests that, for design purposes, it is wise to regard the bearing as a "mixer" in which oil is fed in at one temperature and may be considered as being withdrawn at the mixer temperature.

DESIGN PROCEDURES

Even if, for design purposes, we neglect the amount of heat dissipated by conduction and assume an average viscosity for the oil film, there still remains the difficulty of predicting what this viscosity will be. The designer has now at his disposal a wealth of experimental data which, by reason of the wide differences in experimental conditions, is not easily condensed into a generalized form. There also exist a number of tables or curves which have been calculated from theory. These, however, take the form of rather complex functions which are not easily manipulated to form a generalized treatment. A useful approximation [55] has been developed by Ocvirk to a stage which provides useful algebraic expression which can be manipulated in the course of a search for the best design for a given set of circumstances. Taking Reynolds' equation and neglecting terms covering the departure from linear variation of velocity in the longitudinal direction, an approximation is obtained, the validity of which diminishes as the width of the bearing increases. The modern tendency is to use narrow bearings and the approximation is quite close for breadth-diameter ratios of one half and moderately accurate for breadth-diameter ratios of unity. The following expression relating load-carrying capacity with speed, viscosity and the dimensions of the bearing results:

$$\frac{P}{\eta V}\left(\frac{c}{r}\right)^2\left(\frac{d}{b}\right)^2 = \frac{E\pi}{(1-E^2)^2}\times\sqrt{1+0.621\,E^2}$$

P=load per inch breadth
η=viscosity
V=peripheral velocity of shaft
c=radial clearance
r=radius of shaft
d=diameter of shaft
b=breadth of shaft
E=eccentricity ratio

Mention of breadth-diameter ratio introduces one of the major anomalies of this subject. On the basis of iso-viscous theory, the optimum breadth-diameter ratio is usually calculated [81,41] to be unity or over. However, modern practice, particularly with high-speed bearings, indicates that a shorter bearing is desirable.[4,27,86] It is likely that the reason for the practicability of the shorter bearing arises from factors which are not taken into account in the simple theory, such as deflection of the shaft and thermal aspects.

In solving the cardinal problem of bearing design, the determination of effective viscosity of operation, it has generally been the practice to neglect the heat conducted away through the bearing shell and to draw up some form of heat balance [37,46,75,74,36] between the heat dissipated in friction and the amount carried away by a lubricant. A difficulty here is the prediction of oil flow. Most workers [49,90,16] have divided this flow into two components, one arising from the hydrodynamic action of the bearing itself and the other being governed by the pressure used to force oil into the bearing. It has not however been demonstrated that these two aspects are unconnected. In particular, as indicated earlier, it is possible that the extent of the oil film and indeed the volume of oil subject to hydrodynamic action may well be determined to a greater or lesser extent by the pressure of supply at least up to the value giving a complete film at the point of maximum film thickness. Over the range which they investigated, Du Bois and Ocvirk [24] were able to provide an expression for oil flow based on a parameter which included the feed pressure in the denominator. Oil flow varied with feed pressure, sometimes giving higher and sometimes lower rates of flow than that predicted by their approximate theory. It is reasonable to assume that the excess amounts were due to the action of the supply pressure in forcing oil outwards at the sides of the bearing in the unloaded region and that the deficiences were due to the supply pressure being insufficient to fill a bearing and to give a complete film at the point of convergence, which was one of the basic assumptions of their theory. Selecting from this curve the value of the parameter which corresponds with the theoretical oil flow, it is possible to derive a simple expression connecting the pressure required to give the theoretical flow with other design data. Thus supply pressure becomes a factor to be determined as part of the design procedure and, this having been done, the remainder of the procedure may be based on the premise

that flow rate will accord with theory. It must be noted that the results obtained by Cole and Hughes over a wider range are not interpretable in the simple manner demonstrated by Du Bois and Ocvirk. Some study has been made of "starved" bearings.[29,91]

Having obtained expressions for oil flow and friction, it is possible to show that an equilibrium temperature exists, the magnitude of which depends on the appropriate design parameters. Oil flow increases with eccentricity to a greater extent than friction force which leads to rapid re-establishment of equilibrium after a disturbance in conditions. Consider a bearing operating under a certain load and at a certain eccentricity in circumstances when the oil supply is insufficient to carry away the heat generated by friction. This will have two effects, the reduction in viscosity will lead to an increase in eccentricity and will also result in a reduction in friction. The increase in eccentricity will result in the increase in oil flow so that a new equilibrium will be reached rapidly.

If the friction of the bearing is estimated by a slight further approximation of Ocvirk's equation suggested by Barwell,[3] the minimum value of clearance required to enable a bearing to operate in any one set of conditions may be determined. This minimum occurs at a definite value of eccentricity and from this it is possible to derive an expression which determines the minimum breadth of the bearing required to carry the load.

PERIODIC LOADING

The foregoing remarks relate to bearings which are subject to a constant load in a fixed direction. When the load rotates, it can be shown that the equivalent steady load is represented by the expression:

$$P_1\left(1-2\frac{\omega_1}{\omega}\right)$$

where P_1=magnitude of rotating load
ω_1=speed of angular rotation of load
and ω speed of shaft

It has been demonstrated by the visual method [16] that the oil film is similar in behavior to that arising from steady load but that it rotates in conformity with rotation of the load. It is thus apparent that a critical condition exists when the velocity of the applied load is equal to half the operational speed. Under these circumstances, theory predicts a zero load-carrying capacity and experiment confirms that operation under these conditions leads to a dangerously high eccentricity.[20] When load varies in magnitude but remains constant in direction, that is reciprocating load, similar laws apply and indeed Shawki [68,69] has shown how vectorial analysis may be applied to bearings. His analysis is capable of further development insofar as he assumes the existence of a continuous film, whereas in practice the film will rupture. Instances of imperfect behavior of bearings may be attributable to the load vector moving at half shaft speed for only a comparatively short period of the load cycle. Studies of bearings under dynamic loads have been made by several workers [38,71,79,8] and under steady load with oscillating motion.[2] The degree of flexibility of the bearings may have a significant effect on their response to rotating loads.[88]

BEARING WHIRL

One of the most troublesome problems is bearing vibration or "whirl." Clearly from the above remarks, a bearing has little capacity to resist the application of loads at half shaft speed and indeed one would expect any instability of operating to be associated with that frequency.[39,33,56,58,63] Whirl at half shaft speed is an inherent characteristic of a complete bearing and may be overcome as a rule by introducing some discontinuity in the film path. If eccentricity due to steady loading exceeds a comparatively low value, whirl of the kind disappears. Moreover, evidence exists that whirl only occurs when the lubricant film is unbroken. When rupture occurs, stable operation is rapidly achieved. Another type of whirl exists which has been shown [54,39,53,58] to be associated with the dynamic properties of the shaft and possibly of the bearing supports. There is a strong tendency for this type of bearing instability to occur when the speed of rotation exceeds twice the natural frequency of the shaft in transverse vibration. This form of whirl may be best overcome by ensuring that the steady load applied to the bearing is sufficient to cause it to operate at high eccentricity.

HYDROSTATIC LUBRICATION

The feasibility of lubricating a bearing hydrodynamically in any given set of circumstances is determined by the possibility of selecting the design parameters, breadth, clearance and viscosity in association with speed and load so as to provide a film thickness of adequate magnitude. In certain cases, either of high load or low speed, it becomes impossible to do this, but it is still possible to obtain the main benefits of fluid film lubrication by arranging to supply fluid to the loaded side of the bearing at a pressure sufficient to balance the applied load. Such hydrostatic bearings have been thoroughly treated by Fuller.[28] It is not necessary for the fluid to be a liquid and very effective bearings have been used which employ air or steam as the pressure medium.[30]

AIR BEARINGS

The increasing tendency toward higher speeds for rotating machinery renders it possible for air and other gases to be used as lubricants in the conventional hydrodynamic manner. Installation of air bearings may be a matter of great simplicity because they will aspirate air from the surroundings without any auxiliary feeding equipment whatsoever. Subject to consideration of compressibility,[19,83,84,1,43,23] the normal laws of hydrodynamics apply and it has

been estimated [18] that a load corresponding to 1 p.s.i. per 1,000 rpm is a useful criterion for determining whether or not an air bearing shall be employed.

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TETSUO NISHIYAMA

LIFTING-LINE THEORY OF THE SUBMERGED HYDROFOIL OF FINITE SPAN

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studied Naval Architecture at the Department of Naval Architecture of Tokyo University in Tokyo, Japan from 1944-1947. After several post-graduate courses, he has become an Assistant Professor in the Department of Mechanical Engineering of Tohoku University in Sendai. His work is connected with general hydromechanical problems in Naval Architecture, in particular with wave resistance theory and with the submerged hydrofoil. Professor Nishiyama was the author of the three-part paper titled "Hydrodynamical Investigation on the Submerged Hydrofoil," which appeared in the August 1958, November 1958, and February 1959 editions of THE JOURNAL.

PART I

A calculating method for obtaining hydrodynamical characteristics of the submerged hydrofoil of finite span.

SYMBOLS

C = speed of advance
f = immersion
t = chord length
b = span
λ = aspect ratio
C_a = lift coefficient
C_w = resistance coefficient
w = coefficient showing the influence of viscosity on the lift
Γ = circulation
γ = non-dimensional circulation

The suffix ∞ means the corresponding value in an infinite fluid and the dash denotes the corresponding value in the two dimensional case.

INTRODUCTION

From the viewpoint of the direct application to practical problems, the theory of the submerged hydrofoil of finite span is of extreme importance. Up-to-date some theoretical treatments of the submerged hydrofoil as a three dimensional hydrodynamical problem have been published. These researches are worked out by Weinig,[1] Mauro[2] and Wu.[3] However, of these works, Wu's treatment[3] seems to be the most prominent since both boundary conditions, on the free surface and on the contour of the hydrofoil, are taken into account precisely.

Nevertheless it seems that improvement still remains to be made in the following areas:

1. The expression of velocity potential is too complicated to understand the physical meaning of the equation used in the calculation.
2. The method for obtaining the characteristics is too troublesome to adopt from a practical point of view.
3. The flow around the hydrofoil can not be justly represented by arranging the bound vortex to the trailing edge.

In this paper the author, in the direction of improving the above-stated weak points, has developed the lifting-line theory of the submerged hydrofoil of finite span and examined in detail the following items:

Part I. A practical calculating method for obtaining hydrodynamical characteristics of the submerged hydrofoil of finite span.

Part II. A practical calculating method for obtaining hydrodynamical characteristics of the submerged hydrofoil of dihedral angle.

Part III. A practical calculating method for determining the distribution of chord length and attack angle from the optimum distribution of circulation of the submerged hydrofoil.

Part IV. Side wall effect of an experimental tank

on the characteristics of the submerged hydrofoil.

Part I will be covered in this issue of The JOURNAL. The remaining parts will be included in subsequent issues.

VELOCITY POTENTIAL

We take the origin of coordinate 0 on the still water level with **ox**-axis in the direction of advance, **oy**-axis in the direction of the span and **oz**-axis vertically upward, as shown in Figure 1. Because of a fairly large aspect ratio and small loading, Prandtl's original concept of the lifting-line may be applied to the submerged hydrofoil of finite span; the hydrofoil can be substituted by a bound vortex, namely lifting-line, and the free vortex is situated on the plane parallel to the **xy** plane.

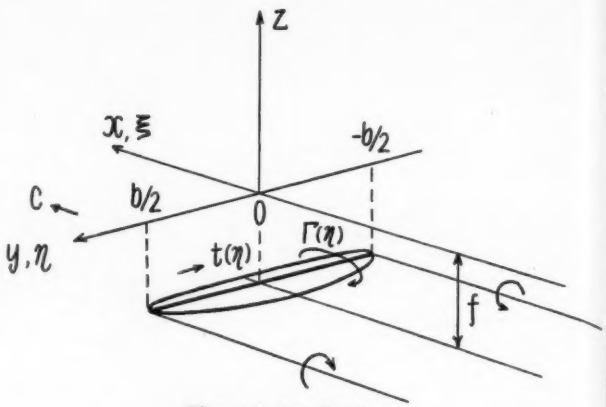

Figure 1. Coordinate.

When a hydrofoil of span b advances in an infinite fluid with the constant speed C at the distance f from the origin, the velocity potential is given by

$$\Phi_\infty=\frac{1}{4\pi}\int_{-\infty}^{0}d\xi\int_{-b/2}^{b/2}\Gamma(\eta)\frac{\partial}{\partial z}\left\{\frac{1}{\sqrt{(x-\xi)^2+(y-\eta)^2+(z+f)^2}}\right\}d\eta \quad \ldots\ldots\ldots (1)$$

Differentiating by z and then integrating by ξ, (1) can be transformed into the form

$$\Phi_\infty=-\frac{i}{8\pi^2}\int_{-b/2}^{b/2}\Gamma(\eta)d\eta\int_{-\pi}^{\pi}\sec\theta d\theta\int_0^\infty e^{-K(z+f)+iK\tilde{w}}dK$$

$$-\frac{1}{4\pi}\int_{-b/2}^{b/2}\Gamma(\eta)d\eta\int_0^\infty e^{-u(z+f)}\cos u(y-\eta)du \quad \ldots\ldots\ldots (1')$$

where $$\tilde{w}=x\cos\theta+(y-\eta)\sin\theta$$

As the second term does not include the variable x, it may be interpreted that the first term represents the fluid motion by the bound vortex and the second term by the free vortex.

When we denote the velocity potential of the submerged hydrofoil Φ, the boundary condition on the free surface can be given by

$$\frac{\partial^2\Phi}{\partial x^2}+K_0\frac{\partial\Phi}{\partial z}-\mu\frac{\partial\Phi}{\partial x}=0; \qquad K_0=g/C^2 \quad \ldots\ldots\ldots (2)$$

Then the velocity potential can be expressed in the following form, from (1') and (2):

$$\Phi=\Phi_\infty+\Phi_1+\Phi_2 \quad \ldots\ldots\ldots (3)$$

$$\Phi_1=\frac{i}{8\pi^2}\int_{-b/2}^{b/2}\Gamma(\eta)d\eta\int_{-\pi}^{\pi}\sec\theta d\theta\int_0^\infty e^{-K(f-z)+iK\tilde{w}}dK$$

$$-\frac{1}{4\pi}\int_{-b/2}^{b/2}\Gamma(\eta)d\eta\int_0^\infty e^{-u(f-z)}\cos u(y-\eta)du \quad \ldots\ldots\ldots (4)$$

$$\Phi_2=\frac{i}{8\pi^2}K_0\int_{-b/2}^{b/2}\Gamma(\eta)d\eta\int_{-\pi}^{\pi}\sec^3\theta d\theta\int_0^\infty\frac{e^{-K(f+z)+iK\tilde{w}}}{K-K_0\sec^2\theta+i\mu\sec\theta}dK \quad \ldots\ldots\ldots (5)$$

where the real part is to be taken, and the Rayleigh's viscosity coefficient μ is to be set equal to zero after serving its purpose.

The velocity potential Φ_1 is the image of Φ_∞ when the free surface is conceived as a fixed boundary; the first and second terms represent the fluid motion by the bound and free vortex respectively at the image point. The velocity potential Φ_2 represents the wave disturbance.

Now we transform Φ_2 by applying the contour integration:

For $\widetilde{w}>0$

$$\Phi_2=\frac{K_0}{2\pi^2}\int_{-b/2}^{b/2}\Gamma(\eta)d\eta\int_{\frac{\pi}{2}+\theta_0}^{\frac{\pi}{2}}\int_0^{\infty}\frac{m\sin m(f-z)+K_0\sec^2\theta\cos m(f-z)}{m^2+K_0^2\sec^4\theta}\sec^3\theta e^{-K\widetilde{w}}d\theta dm \quad (6)$$

For $\widetilde{w}<0$

$$\Phi_2=-\frac{K_0}{2\pi^2}\int_{-b/2}^{b/2}\Gamma(\eta)d\eta\int_{\frac{-\pi}{2}}^{\frac{\pi}{2}+\theta_0}\int_0^{\infty}\frac{m\sin m(f-z)+K_0\sec^2\theta\cos m(f-z)}{m^2+K_0^2\sec^4\theta}\sec^3\theta e^{K\widetilde{w}}d\theta dm$$

$$+\frac{K_0}{\pi}\int_{-b/2}^{b/2}\Gamma(\eta)d\eta\int_{\frac{-\pi}{2}}^{\frac{\pi}{2}+\theta_0}\sec^3\theta e^{-K_0(f-z)\sec^2\theta}\cos(K_0\widetilde{w}\sec^2\theta)d\theta \quad \ldots\ldots\ldots\ldots (7)$$

where $$\theta_0=\tan^{-1}\frac{y-n}{x}$$

(6) and the first term of (7) represent the local symmetrical disturbance which can be observed only in the vicinity of the hydrofoil, and the second term of (7) represents the regular wave motion to the rearward of the hydrofoil.

We transform the second term of (7) by putting u equal to $\tan\theta$

$$[\Phi_2]_{wave}=\frac{K_0}{\pi}\int_{-b/2}^{b/2}\Gamma(\eta)d\eta\int_{-\infty}^{-\cot\theta_0}(u^2+1)^{1/2}e^{-K_0(f-z)(1+u^2)}\cos[K_0(1+u^2)^{1/2}\{x+(y-\eta)u\}]du$$

$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7')$

Generally the speed of advance of the submerged hydrofoil is extremely high, therefore it can be easily shown that the contribution to the integral (7′) is exclusively due to the larger values of u. Then paying attention only to the vicinity of the hydrofoil, we obtain

$$\lim_{\substack{K_0\to 0\\ x\sim 0}}[\Phi_2]_{wave}=\frac{K_0}{\pi}\int_{-b/2}^{b/2}\Gamma(\eta)d\eta\int_{-\infty}^{-\cot\theta_0}\cos\{K_0(y-\eta)u^2\}e^{-K_0(f-z)u^2}udu \quad \ldots\ldots\ldots (7'')$$

Transforming (7″) by putting K_0u^2 equal to t, we have

$$\lim_{\substack{K_0\to 0\\ x\sim 0}}[\Phi_2]_{wave}=-\frac{1}{2\pi}\int_{-b/2}^{b/2}\Gamma(\eta)d\eta\int_0^{\infty}\cos\{t(y-\eta)\}e^{-t(f-z)}dt \quad \ldots\ldots\ldots\ldots\ldots\ldots (7''')$$

Now comparing (7‴) with (4), the following relation holds

$$\lim_{\substack{K_0\to 0\\ x\sim 0}}[\Phi_2]_{wave}=2\times[\text{the 2nd term of }\Phi_1] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

In other words the velocity potential of the regular wave at an extremely high speed is equal to twice that of the image free vortex; or the wave motion immediately after the hydrofoil gradually approaches the free vortex motion as the speed becomes higher.

On the other hand the corresponding relation[4] in a two dimensional case is

$$\lim_{\substack{K_0\to 0\\ x\sim 0}}[\Phi_2]_{wave}=0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

That is, the regular wave motion immediately after the two dimensional hydrofoil can not be observed at all.

The relations (8) and (9) will be useful for considering the relation between the induced and wave resistances and the variation of the wave resistance with the aspect ratio.

INDUCED VELOCITY

Now we consider in detail the induced velocity before examining the forces of the hydrofoil.

Vertical induced velocity

Differentiating (3) by z we obtain

$$w_z=\frac{1}{4\pi}\int_{-b/2}^{b/2}\frac{d\Gamma(\eta)}{d\eta}\frac{d\eta}{y-\eta}-\frac{1}{4\pi}\int_{-b/2}^{b/2}\Gamma(\eta)d\eta\int_0^\infty ue^{-2uf}\cos\{u(y-\eta)\}du$$
$$+\frac{K_0^2}{\pi}\int_{-b/2}^{b/2}\Gamma(\eta)d\eta\int_0^{\pi/2}\sec^5\theta\cdot e^{-2K_0f\sec^2\theta}\cos\{K_0\sec^2\theta\cdot(y-\eta)\sin\theta\}d\theta \quad \ldots\ldots (10)$$

Evaluating the integral after altering the variable of the integration, (10) can be reduced to

$$w_z=\frac{1}{4\pi}\int_{-b/2}^{b/2}\frac{d\Gamma(\eta)}{d\eta}\frac{d\eta}{y-\eta}+\frac{1}{4\pi}\int_{-b/2}^{b/2}\Gamma(\eta)\underline{\overline{K}}(y-\eta)d\eta \quad \ldots\ldots (10')$$

where

$$\underline{\overline{K}}(y)=-\frac{4f^2-y^2}{4f^2+y^2}+\frac{K_0^2}{2}e^{-K_0f}\left[\left(1+\frac{4f^2}{y^2+4f^2}\right)\underline{\overline{K}}_0\right.$$
$$\left.+2\left\{\frac{2f}{\sqrt{y^2+4f^2}}-\frac{1}{K_0\sqrt{y^2+4f^2}}+\frac{8f^2}{K_0(y^2+4f^2)^{3/2}}\right\}\underline{\overline{K}}_1\right] \quad \ldots\ldots (11)$$

with the modified Bessel functions of the second kind $\underline{\overline{K}}_0$ and $\underline{\overline{K}}_1$, the argument of which is $\frac{K_0}{2}(y^2+4f^2)^{1/2}$.

(11) can be transformed for extremely low and high speeds as

$$\lim_{K_0\to 0}\underline{\overline{K}}(y)=-\lim_{K_0\to\infty}\underline{\overline{K}}(y)=\frac{4f^2-y^2}{(y^2+4f^2)^2} \quad \ldots\ldots (11')$$

Therefore the vertical induced velocity is caused by the regular wave motion and free vortex motion, and further, decreases at extremely low speeds and on the contrary increases at extremely high speeds. Correspondingly to this, the effective angle of attack increases at extremely low speeds and decreases at extremely high speeds.

Horizontal induced velocity

As easily shown from (3), the horizontal induced velocity has no relation at all with the free vortex. Therefore if the aspect ratio is very large, the horizontal induced velocity could be replaced by that of the two dimensional case.

The horizontal induced velocity in two dimensions[4] is given by

$$w_x'=-\frac{\Gamma}{2\pi}\int_0^\infty e^{-K(f-y)+iKx}dK-\frac{\Gamma}{2\pi}2K_0\int_0^\infty\frac{e^{-K(f-y)+iKx}}{K-K_0+i\mu}dK \quad \ldots\ldots (12)$$

Applying the Fourier's double integral theorem to (12) we obtain

$$w_x'=-\frac{1}{2\pi^2}\int\Gamma(\eta)d\eta\int_0^\infty\cos\beta(y-\eta)d\beta\int_0^\infty e^{-\alpha(f-y)+i\alpha x}d\alpha$$
$$-\frac{1}{2\pi^2}2K_0\int\Gamma(\eta)d\eta\int_0^\infty\cos\beta(y-\eta)d\beta\int_0^\infty\frac{e^{-\alpha(f-y)+i\alpha x}}{\alpha-K_0+i\mu}d\alpha \quad \ldots\ldots (12')$$

Then putting $\alpha=K\cos\theta$ and $\beta=K\sin\theta$, (12′) can be transformed into

$$w_x'=-\frac{1}{8\pi^2}\left[\int\Gamma(\eta)d\eta\int_{-\pi}^{\pi}d\theta\int_0^\infty Ke^{-K(f-z)\cos\theta+iK\{x\cos\theta+(y-\eta)\sin\theta\}}dK\right.$$
$$\left.+2K_0\int\Gamma(\eta)d\eta\int_{-\pi}^{\pi}\sec\theta d\theta\int_0^\infty\frac{Ke^{-K(f-z)\cos\theta+iK\{x\cos\theta+(y-\eta)\sin\theta\}}}{K-K_0\sec\theta+i\mu\sec\theta}dK\right] \quad \ldots\ldots (12'')$$

As it can be easily demonstrated that the contribution to the integral with respect to θ is mainly due to the extremely small value of θ if the aspect ratio is very large, (12″) is reduced to

$$w_x' \approx -\frac{1}{8\pi^2}\left[\int\Gamma(\eta)d\eta\int_{-\pi}^{\pi}d\theta\int_0^{\infty}Ke^{-K(f-z)+iK\{x\cos\theta+(y-\eta)\sin\theta\}}dK\right.$$

$$\left.+2K_0\int\Gamma(\eta)d\eta\int_{-\pi}^{\pi}\sec\theta d\theta\int_0^{\infty}\frac{Ke^{-K(f-z)+iK\{x\cos\theta+(y-\eta)\sin\theta\}}}{K-K_0\sec^2\theta+i\mu\sec\theta}dK\right] \quad \ldots\ldots(12''')$$

On the other hand, by directly differentiating (3) with respect to x, (12′′′) can also be obtained. Therefore the relation holds[4]:

$$w_x=w_x'=\frac{\Gamma(\eta)}{\pi}\left\{\frac{1}{4f}-K_0e^{-2K_0f}Li(e^{2K_0f})\right\} \quad \ldots\ldots(13)$$

where Li is a Logarithmic integral.
In short we can see that the horizontal induced velocity depends only on the local symmetrical disturbance and the bound vortex motion, and is negligibly small compared with the advancing speed of the hydrofoil.

INTEGRAL EQUATION

The circulation in two dimensions is given by

$$\Gamma=\frac{m_0}{2}tC\alpha;\quad m_0=2\pi w \quad \ldots\ldots(14)$$

Then the circulation on the span of the submerged hydrofoil is given by

$$\Gamma(y)=\frac{m_0}{2}\,t(y)\{C-w_x(y)\}\left\{\alpha(y)-\frac{w_z(y)}{C-w_x(y)}\right\} \quad \ldots\ldots(15)$$

On the other hand the circulation in an infinite fluid is given by

$$\Gamma_\infty(y)=\frac{m_0}{2}t(y)C\left\{\alpha(y)-\frac{w_{z\infty}(y)}{C}\right\} \quad \ldots\ldots(16)$$

Taking a fairly large aspect ratio and small loading into account, and neglecting the 2nd order, we have from (10′), (15) and (16),

$$\Gamma(y)=-\frac{m_0}{8\pi}t(y)\int_{-b/2}^{b/2}\Gamma(\eta).\underline{\overline{K}}(y-\eta)d\eta+\Gamma_\infty(y) \quad \ldots\ldots(17)$$

When the circulation in an infinite fluid is given, the corresponding value in the submerged condition can be known by solving this integral equation.

From the circulation, the lift and resistance can be obtained respectively by

$$L=\rho C\int_{-b/2}^{b/2}\Gamma(\eta)d\eta \quad \ldots\ldots(18)$$

$$D=\rho\int_{-b/2}^{b/2}\Gamma(\eta)w_z(\eta)d\eta \quad \ldots\ldots(19)$$

NUMERICAL SOLUTION

An analytical solution for this integral equation (17) is too troublesome to obtain. However from the fact that (17) is of Fredholm's type of the second kind and the kernal $\underline{\overline{K}}$ (y-η) is regular, we can solve numerically by applying Nyström's method.

Putting

$$\Gamma(y)=2bC\gamma(y) \quad \text{and} \quad l_\infty(y)=2bC\,{}_\infty(y)$$

(17) is reduced to

$$\gamma(y)=-\frac{m_0}{16\pi}\frac{t(y)}{b}\int_{-1}^{1}\gamma(\eta)\underline{\overline{K}}(y-\eta)d\eta+\gamma_\infty(y);|y|\leqq 1 \quad \ldots\ldots(17')$$

where

$$\underline{\bar{K}}(y)=-\frac{4\delta^2\beta^2-\frac{1}{4}\beta^4y^2}{\left\{4\delta^2+\frac{1}{4}\beta^2y^2\right\}^2}+2(K_0f)^2\left(\frac{\beta}{\delta}\right)^2 e^{-K_0f}\left[\left\{1+\frac{4\delta^2}{4\delta^2+\frac{1}{4}\beta^2y^2}\right\}\times \underline{K_0}\left(\frac{K_0f}{2\delta}\sqrt{4\delta^2+\frac{1}{4}\beta^2y^2}\right)\right.$$
$$+2\left\{\frac{2\delta}{\sqrt{4\delta^2+\frac{1}{4}\beta^2y^2}}-\frac{1}{K_0f}\frac{\delta}{\sqrt{4\delta^2+\frac{1}{4}\beta^2y^2}}\right.$$
$$\left.\left.+\frac{8\delta^2}{K_0f\left\{4\delta^2+\frac{1}{4}\beta^2y^2\right\}^{3/2}}\right\}\underline{K_1}\left(\frac{K_0f}{2\delta}\sqrt{4\delta^2+\frac{1}{4}\beta^2y^2}\right)\right] \quad \text{.....(17″)}$$

with $\delta=f/t_{y=0}$ and $\beta=b/t_{y=0}$

Then by Nyström's method (17′) is transformed into

$$\gamma(y_j)=-\frac{m_0}{8\pi b}t(y_j)\sum_{1}^{n}a_i{}^n\gamma(\eta_i)\underline{K}(y_j-\eta_i)+\gamma_\infty(y_j) \quad \text{.....(17‴)}$$

Taking seven points over the span after Glauert's method, seven simultaneous equations are obtained, but we can reduce them to four simultaneous equations owing to the symmetry of the distribution of circulation with respect to the central plane. Then the coordinates η_i and coefficients $a_i{}^n$ in the numerical calculation should be taken as follows

$$\begin{pmatrix}\eta_1\\ \eta_7\end{pmatrix}=\pm0.94910 \qquad \begin{pmatrix}a_1{}^7\\ a_7{}^7\end{pmatrix}=0.06474$$

$$\begin{pmatrix}\eta_2\\ \eta_6\end{pmatrix}=\pm0.74153 \qquad \begin{pmatrix}a_2{}^7\\ a_6{}^7\end{pmatrix}=0.13985$$

$$\begin{pmatrix}\eta_3\\ \eta_5\end{pmatrix}=\pm0.40584 \qquad \begin{pmatrix}a_3{}^7\\ a_5{}^7\end{pmatrix}=0.19091$$

$$\eta_4=0 \qquad a_4{}^7=0.20898$$

Thus using the numerical value of γ (y), the lift and resistance can be also obtained from (18) and (19) by a similar numerical procedure.

NUMERICAL EXAMPLES

Numerical calculations are carried out for the following cases:

Aspect ratio	$\lambda=5$ and 7
Circulation	$\gamma_\infty(\eta)=\frac{C_{a\infty}}{\pi\lambda}\sqrt{1-\eta^2}$
Immersion	$f/t_{y=0}=1$
Coefficient	$w=0.85$

The distribution of circulation over the span is shown in Figure 2. Except at extremely low speeds, we find the effective circulation distribution only small compared with that in an infinite fluid for the speed range of interest. The variation of the lift and resistance with the Froude number are shown for three aspect ratios $\lambda=5$, 7 and ∞ in Figures 3 and 4 respectively; from which we see that, compared with the corresponding value in the two dimensional case, the effect of the free surface on the lift and wave resistance decreases as the aspect ratio becomes

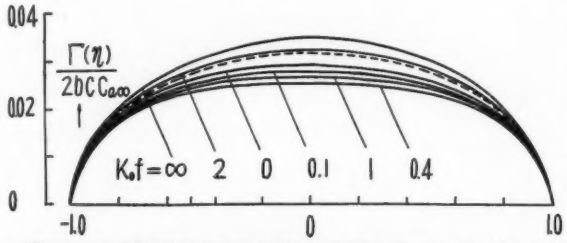

Figure 2. Effective Distribution of Circulation for the Aspect Ratio 5 (Dotted line shows the corresponding value in an infinite fluid.)

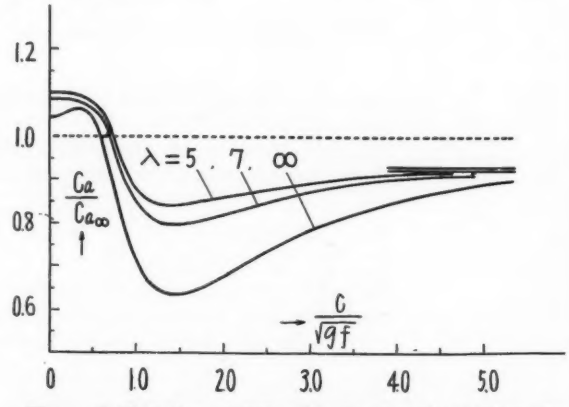

Figure 3. Variation of Lift with the Froude Number for the Aspect Ratios 5, 7 and ∞. (Dotted line shows the corresponding value in an infinite fluid.)

smaller, and also the wave resistance has a limiting value at extremely high speeds. The reason for the latter may be explained by the relation (8).

In order to confirm the accuracy of these results for n=7, we compare the corresponding results for n=9. The distribution of circulation is shown in Figure 5 and the lift is as follows:

	$\Gamma(0)/2bC\,C_{a\infty}$	$C_a/C_{a\infty}$
n=7	0.03869	0.8780
n=9	0.03906	0.8823

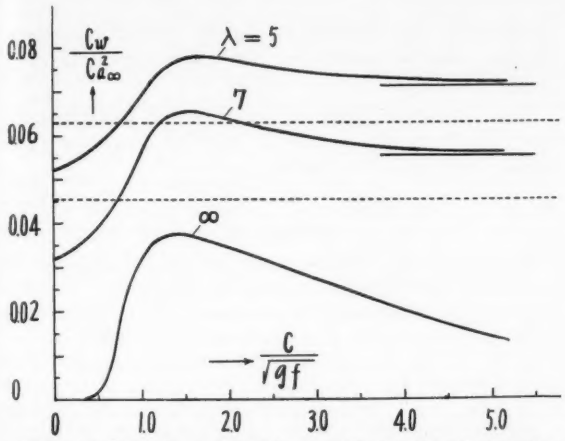

Figure 4. Variation of Resistance with the Froude Number for the Aspect Ratios 5, 7 and Infinity. (Dotted line shows the corresponding value in an infinite fluid.)

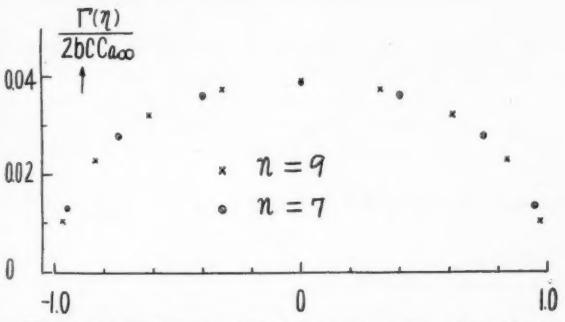

Figure 5. Effective Distribution of Circulation for $K_0f=0.1$ and $\lambda=7$.

From these we see that the results for n=7 are sufficiently satisfying for practical purposes.

COMPARISON

In order to compare with the experimental results[5] published recently by NACA, we arrange our calculations as follows:

1. The replaced lifting-line is reckoned as a horizontal bound vortex through the quarter-chord point from the leading edge, because the center of pressure in the ordinary hydrofoil section almost coincides with this point.

2. The coefficient showing the influence of viscosity takes a value[6] between 0.80 and 0.90; therefore we select 0.85 as a mean value.

Comparisons are made for the two conditions as follows:

aspect ratio	immersion
10	0.84
4	0.59

The lift and resistance are shown in Figures 6 and 7, and Figures 8 and 9, respectively. Surveying these

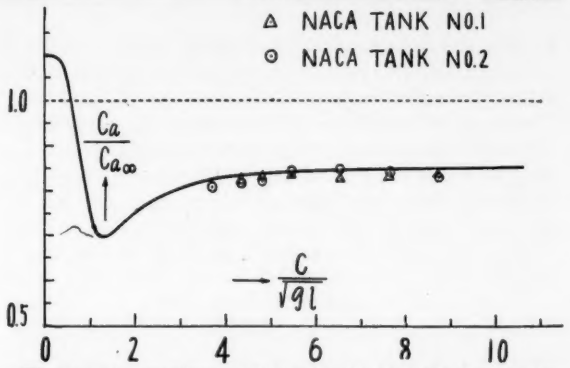

Figure 6. Comparison of Lift with NACA Data for the Aspect Ratio 10.

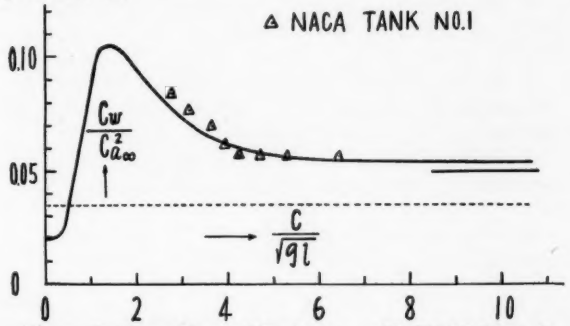

Figure 7. Comparison of Resistance with NACA Data for the Aspect Ratio 10.

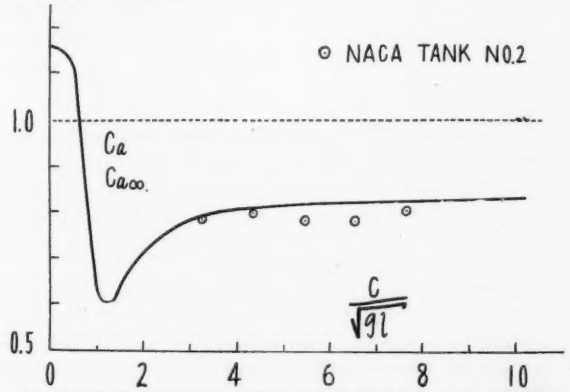

Figure 8. Comparison of Lift with NACA Data for the Aspect Ratio 4.

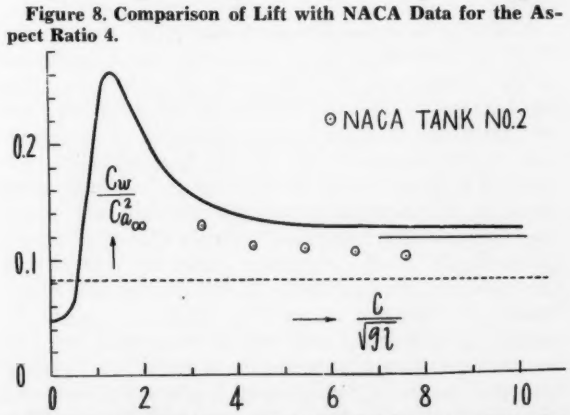

Figure 9. Comparison of Resistance with NACA Data for the Aspect Ratio 4.

results, the calculated values are in good accordance with the experiment for an aspect ratio of 10 but larger than the experiment for an aspect ratio of 4. The cause of the latter may be interpreted as the effect of the lifting-surface. At any rate, taking into account that the aspect ratio of the submerged hydrofoil is relatively large and almost 9 as a mean, it can be safely said that this present method gives a satisfying result for the normal condition of operation.

CONCLUSIONS

In this paper the lifting-line theory of the submerged hydrofoil of finite span is developed. The main problems treated are as follows.

1. Introducing Rayleigh's viscosity coefficient, the velocity potential is represented in a relatively simple form and its physical mean is illustrated.
2. A practical calculating method for obtaining the characteristics is proposed by applying Nyström's method to the integral equation of circulation.
3. By the numerical examples the effect of the aspect ratio on the lift and resistance is clarified. Also, comparing the theoretical value with the experimental, the reliability of the proposed method is confirmed.

The author wishes to express his gratitude to Prof. F. Numachi and Prof S. Fuchizawa for their many inspiring discussions.

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DISCUSSION

"Lifting-Line Theory of the Submerged Hydrofoil of Finite Span"

PART I

by Tetsuo Nishiyama

By Dr. B. Silverstein, Ship Design Division
Bureau of Ships

In this paper, Professor Nishiyama studies an important practical problem in connection with hydrofoils—the finite wing. As is pointed out, Wu's treatment of this problem is elegant but is not in the form that is easily used by the designer; there are a number of integrals that are intractable.

Before examining Professor Nishiyama's work, it is useful to summarize the background of the lifting-line theory, due to Prandtl, which both Wu and Nishiyama have extended to consider free surface effects.

It should be re-emphasized that all of the studies of lifting surfaces (wings, hydrofoils, etc.) are based on the vortex, and systems of vortices. These vortices can be seen in flow pictures of lifting wings, but for our purposes they can be considered as a special sort of mathematical singularity. It may be considered as a point that induces a special velocity field about it. All particles travel in a circular path about the vortex with a tangential velocity that is inversely proportional to the distance from the vortex (as the path is circular there is, of course, no radial velocity). There is a subtlety here that might be noted; the particular relation of tangential velocity to distance from the vortex is a result of insuring that the motion is "irrotational," where the laws and theorems of hydrodynamics are well-known. The particles, though moving in a circular path, do not "rotate"; they stay in position very much like the cars on a ferris wheel.

If we construct any closed curve surrounding a vortex and integrate the tangential velocity from any point on the curve, traversing this curve back to the same point, we derive the circulation, Γ, which has units of feet squared per second.

The laws governing vortices have been studied by many men including Helmholtz, Lord Kelvin and Kutta. The latter developed the famous theorem of lift which sparked the great interest in vortices and their associated circulations:

Lift per unit of span = Mass density × velocity × circulation,

or $$L=\rho V\Gamma$$

Any explanation of vortex representations for lifting wings must satisfy the laws of vortex behavior, such as circulation is a constant with respect to time, vortex filaments must close, etc.

Now let us consider a hydrofoil at an angle of attack, moving with constant velocity through an ideal fluid. Immediately, a so-called starting vortex (parallel to the span) leaves the wing. The strength of this vortex is equal and opposite in sign to the

bound vortex remaining on the foil: This is convenient, as one of the laws to be satisfied is that the circulation is constant with time. Both vortices (the starting and the bound) extend to infinity and thus satisfy another law that vortex filaments must close.

The finite wing, in order to satisfy this latter law, must shed vortices at each wing tip; this is called the trailing vortex. When the starting vortex is far downstream the system consisting of a bound vortex on the foil and the trailing vortex form a representation that looks somewhat like a horseshoe, and thus is commonly referred to as a horseshoe vortex field.

This leads to a fundamental difference between the two-dimensional and the finite foil. For the former, Γ is a constant with respect to the span. For the latter, the circulation must vanish at the foil tips and thus must vary with span—note, for example, in equation (1) of this paper that Γ is a function of η as it varies from one tip to the other.

The horseshoe vortex system no longer preserves the symmetry of flow ahead of the foil compared to that aft. The trailing vortices plus the bound vortex induce a downward inclination of the velocity field; the vertical component is the well-known downwash. This causes a tipping aft of the resultant force vector on the foil, which can be attributed to an "induced drag." As is well-known, this induced drag is, of course, zero for two-dimensional foils and is a minimum on a finite wing that has an elliptical spanwise distribution of circulation of the bound vortex.

This concept of replacing the finite wing by bound trailing and starting vortices was first developed mathematically by Prandtl and thus bears his name as Prandtl's lifting-line theory. It should be noted that this theory is applicable only for large aspect ratios and small to moderate loading. For heavily loaded foils, a lifting surface theory is needed.

Professor Nishiyama uses the lifting line theory in his representation of the wing. He then presents the total velocity potential, including the effects of the free surface. From this he derives the induced velocities which are needed for the determination of Γ and then the lift and drag.

The results appear extremely useful and the experimental data check nicely with the theory. The real value does, of course, depend on the ease and speed of application to hydrofoil design. This will require a number of calculations to check existing data. In this connection, this paper and the next one (treating foils having a dihedral angle) should provide excellent working material for the hydrofoil designer.

The project to drill through the crust of the earth—Project Moho—will require a considerable amount of ingenuity to develop the equipment and technique required. The American plan projected presently envisions drilling from a marine rig, since the Mohovoricic Discontinuity lies about 16,000 feet below the sea floor in certain Pacific areas, while elsewhere, a much deeper hole would be required. This depth hole, on dry land, would be feasible with present equipment. However, in the Pacific locations, the ocean is 15,000 to 18,000 feet deep. This means handling unprecedented lengths of drill strings—over 30,000 feet long. Alternatively, a means for applying power directly to the drill pipe at the ocean bottom may be feasible. It appears that a new design drill barge will be required to meet the stringent requirements. The Soviet Academy of Sciences is reported to have set up a new branch in order to solve the necessary problems and be the first to accomplish the project.

—from SCIENCE NEWS LETTER
June 6, 1959

A standard conversion from centimeters to inches has been adopted by the "inch-using" countries as of July 1 this year. Previously two values were in use among these countries—both were used within some of the countries. The difference amounted to less than a hundred-thousandth of an inch, but in the modern age of ultra-accuracy this was no longer tolerable. The new International Standard now provides an inch standard of exactly 2.54 centimeters.

—from MACHINERY
May, 1959

The B. F. Goodrich Company has developed a process for the production of flexible magnets. Made of specially compounded vinyl plastic, the material is producible in continuous lengths in a wide range of shapes and cross sections. Cutting it does not impair its magnetic qualities. The material is attracted to ferrous objects or to itself, and is capable of being magnetized in any direction.

—from MECHANICAL ENGINEERING
June, 1959

In a paper presented to the Society of Automotive Engineers, F. E. Rom and P. G. Johnson examined the requirements of a nuclear rocket for space exploration. It was noted that 130 million horsepower would be required to place a 500,000 lb. interplanetary vehicle in orbit, while only one thousandth of this power would produce a 0.1g acceleration—sufficient for space missions once the vehicle is in orbit. Therefore reactors of sufficient power to launch the vehicle would have to be several times more powerful than any now known. This dictates the use of chemical propulsion for the initial portion of the flight.

—from S.A.E. JOURNAL
June, 1959

A new method of detecting condenser tube leaks using plastic film has been employed by the Virginia Electric and Power Company. Claimed to permit faster isolation of leaking tubes than the commonly employed pressure tests using soap film or candle flame, the method is applicable to marine use. In this procedure, after the circulating water is drained from the condenser, ordinary household plastic film is placed over the tube ends of one tube sheet, the tube ends being kept wet. Then, with the air ejectors in operation, the other end is covered. A leaking tube will rapidly reveal itself by pulling the plastic film into the tube end.

—from POWER
June, 1959

The use of epoxy resins to form a matrix in which metalic particles can be embedded is attracting increasing attention in the field of engineering materials. Like the technique of powder metallurgy, such an approach offers the possibility of obtaining a combination of properties not possible by ordinary alloying techniques. Low friction materials can be combined in varying proportions to obtain properties most suitable for particular bearing applications. Graphite, molybdenum disulphide, lead, copper, zinc and tin alloys are examples. The possibility of improved radiation shielding is indicated. The use of powdered lead cast in epoxy provides good gamma shielding possibilities, with an advantage over-solid lead slabs in shaping and forming. Casting heavy shielding sections on the erection site may be cheaper and more efficient than transporting and erecting heavy slab sections.

—from INDUSTRIAL LABORATORIES
May, 1959

"THE MARINE ENGINEER & NAVAL ARCHITECT"

HIGH-TORQUE MERCHANT SHIP GEARING

ACKNOWLEDGEMENT

This article was published in the February 1959 edition of "The Marine Engineer and Naval Architect." The author is J. R. G. Braddyll, Principal Assistant Chief of Marine Engine (Steam) Design, Vickers Armstrong, Ltd. The article is an abstract of a paper read before the North East Coast Institution of Engineers and Shipbuilders on 6 January 1959.

THE current trend in tanker design, in which deadweight capacity is being continuously increased, is leading to progressively higher torques on propeller shafts. This is because the propeller efficiency falls off as revolutions increase (unless the ship's speed is correspondingly increased), and because the power required for a given speed increases with the size of the ship. This is illustrated graphically in Figure 1, in which are plotted propeller shaft torque against thousands of tons deadweight for a number of tankers designed during the last ten years. All the points plotted represent ships which have actually been built or ordered with the exception of the 72,000-ton tanker. While the scatter of the points in relation to a fair curve is fairly wide, reflecting various owners' opinions concerning the proper economical speed for their ships, it is fairly clear that a 72,000-ton tanker is likely to require a propeller shaft torque of around 15×10^6 lb. in. and a 100,000-ton tanker (if propelled by a single screw) something approaching 20×10^6 lb. in.

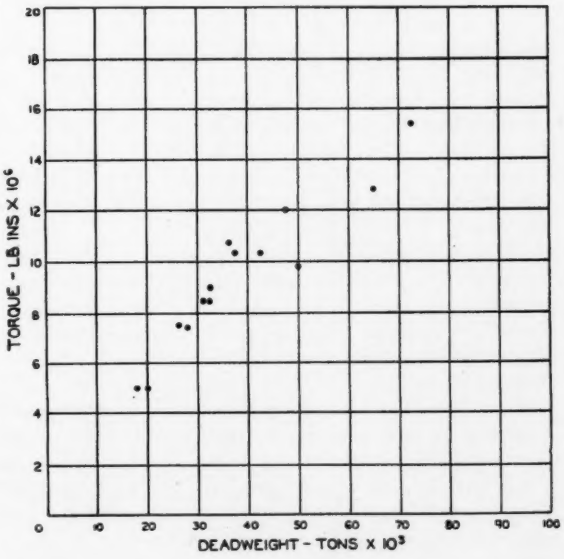

Figure 1. Trend of tanker machinery torque over the past 10 years.

DESIGN CONSIDERATIONS

From considerations of first cost and also efficiency there is a desire to retain the two-turbine single-screw arrangement, and a torque of 12×10^6 lb. in.

(20,000 s.h.p. at 105 r.p.m.) has been handled successfully by gearing of conventional design. Torques of 12.8×10^6 lb. in. (22,000 s.h.p. at 108 r.p.m.) also are programmed for construction in the near future. The trend appears to be continuing, however, to the stage when handling of the torques required for larger tankers will pose a problem for the gear designer, and it may be necessary to break new ground in terms of tooth loading, gear materials or gear configuration.

PROPOSAL FOR 26,500 S.H.P.

By way of example: the guidance specification for a proposed tanker of about 72,000-tons deadweight called for two turbines geared to a single screw, the leading particulars being approximately as follows:

Maximum shaft h.p.	26,500
Propeller r.p.m.	109
H.P. turbine r.p.m.	5,950
L.P. turbine r.p.m.	3,360

A division of power of 12,900 h.p. on the H.P. train and 13,600 h.p. on the L.P. was assumed, based on previous practice designed to produce equal load distribution under service power conditions, and a number of possible gear designs have been prepared and examined. Of these, three have been selected for critical survey here.

TABLE I—GEARING AND MATERIAL PARTICULARS

		First Reduction Gearing				Second Reduction Gearing		
		H.P. Pinion	H.P. Wheel	L.P. Pinion	L.P. Wheel	H.P. Pinion	L.P. Pinion	Main Wheel
Proposal "A"	No. of Elements	1	1	1	1	1	1	1
	Horse Power	12900	12900	13600	13600	12900	13600	26500
	Speed RPM	5950	728	3391	728	728	728	109.5
	No. of Teeth	53	433	93	433	75	75	499
	P.C. Dia. In.	11.679	95.414	20.493	95.414	24.769	24.769	164.795
	Face + Gap In.	22.50 + 3 Gap		22.50 + 3 Gap		49.25 + 3 Gap		
	P.L.S. Ft./Sec.	303		303		79		
	Helix Angle	29° 59′		29° 59′		29° 58′		
	Normal Pitch In.	.60		.60		.90		
	Tooth Load Lb./In.	1040		1096		H.P.-1830 L.P.-1930		
	K Factor	100.0		65.0		H.P.-85.0 L.P.-89.6		
	Material	En. 26	En. 9	En. 26	En. 9	En. 26	En. 26	En. 9
Proposal "B"	No. of Elements	1	1	1	1	1	1	1
	Horse Power	12900	12900	13600	13600	12900	13600	26500
	Speed RPM	5950	723	3359	723	723	723	108.7
	No. of Teeth	35	288	62	288	75	75	499
	P.C. Dia. In.	8.995	74.018	15.934	74.018	24.769	24.769	164.795
	Face + Gap In.	13.75 + 3 Gap		13.75 + 3 Gap		49.25 + 3 Gap		
	P.L.S. Ft./Sec.	234		234		78		
	Helix Angle	29° 58′		29° 58′		29° 58′		
	Normal Pitch In.	.70		.70		.90		
	Tooth Load Lb./In.	2209		2329		H.P.-1843 L.P.-1943		
	K Factor	275.5		177.7		H.P.-85.6 L.P.-90.2		
	Material	En. 36 CH	En. 24 IH	En. 36 CH	En. 24 IH	En. 26	En. 26	En. 9
Proposal "C"	No. of Elements	1	2	1	2	2	2	1
	Horse Power	12900	6450	13600	6800	6450	6800	26500
	Speed RPM	5950	1025	3354	1025	1025	1025	1092
	No. of Teeth	31	180	55	180	60	60	563
	P.C. Dia. In.	6.768	39.297	12.007	39.297	17.620	17.620	165.330
	Face + Gap In.	14.00 + 3 Gap		14.00 + 3 Gap		33.25 + 3 Gap		
	P.L.S. Ft./Sec.	176		176		79		
	Helix Angle	29° 2′		29° 2′		29° 58′		
	Normal Pitch In.	.60		.60		.80		
	Tooth Load Lb./In.	1442		1520		H.P.-1354 L.P.-1428		
	K Factor	249.8		165.3		H.P.-85.1 L.P.-89.7		
	Material	En. 36 CH	En. 24 IH	En. 36 CH	En. 24 IH	En. 26	En. 26	En. 9

TABLE II—MATERIAL SPECIFICATIONS

Material designation	British Standard En. No.	Condition	Tensile Strength Tons/sq. in. min.	Yield Stress Tons/sq. in. min.	Elongation per cent min.	Brinell hardness number
"55" Carbon steel	En. 9	Normalized	45	23	18	201-255
1½% Nickel-chromium-molybdenum steel	En. 24	Induction-hardened and tempered	55 (Core)	—	—	535 (case)
2½% Nickel-chromium-molybdenum steel (high carbon)	En. 26	Hardened and tempered	60	48	17	269-321
3% Nickel-chromium case hardening steel	En. 36A	Carburized oil quenched and tempered	55 (Core)	—	—	565 (case)

Briefly, Proposal "A" embodies conventional gear materials, En.26 for pinions, En.9 for wheels, the tooth loading being in accordance with Lloyd's Rules, the K factor being 100 and 90 on the first and second-reduction gears respectively.

Proposal "B" incorporates the same second-reduction gears as Proposal "A" (K=90), but the first reduction gears are hardened and ground, the K factor being 275.

Proposal "C" employs a dual-tandem gear configuration. The second-reduction gears are of the same materials as "A" and "B" and designed on the same load factor (K=90). The first-reduction gears are hardened and ground, the K factor being 250.

For each of these designs it would be specified that all gears should be to B.S.S. 1807, Grade A1, being finished by shaving, lapping or grinding as appropriate. The leading design particulars are shown in Table I.

The brief specification of materials by their British Standard numbers may be amplified by reference to Table II, which indicates also the condition in which the steels are used. All steels are standard except that En.9 must be ordered with the carbon limited to 0.55 per cent max. (specified 0.5-0.6 per cent) to facilitate satisfactory gear hobbing.

TOOTH FORM

(a) All the gears referred to here are of the double-helical type. This, of course, is standard practice with gears which are not hardened, and there is no difficulty in retaining the practice with hardened pinions. Hardened and ground wheels, however, present a problem because if made in the ordinary way, it will be necessary to provide a gap of 5 or 6 in. between the helices to allow for grinding. The alternative of using single-helical gears has, of course, been considered, but because the thrust bearings are power absorbers and therefore reduce the gearbox efficiency, and because there is not at present available a proven design of conical bearing for taking end thrust, and also because the slewing effect due to the overturning moment on the single-helical gears produces some uncertainties concerning the precise load distribution during operation, it has been preferred to go to the trouble of making wheels having two rims, each capable of removal from its reference while the other is being ground. Such a wheel is indicated in the first-reduction train in Figure 4, but for the larger wheels of Proposal "B" a cast or fabricated steel center would be used. In addition to the cylindrical reference the rims are located by conical dowels, which also transmit the torque, and securing bolts which pass through the dowels.

(b) Figure 2 illustrates the tooth form selected for all the gears referred to above and is of the type having 16 degrees pressure angle and a working depth of 2.4 module. There is a school of thought which believes that, for hardened gears, it is necessary or desirable to go to higher pressure angles to reduce the slide/roll ratio and tendency towards scuffing. The author has indeed been associated with gears having a pressure angle as high as 25 degrees; these being designed specifically as anti-scuffing gears. It is considered, however, that it is highly desirable to retain the maximum possible working degree of flexibility in the gear teeth, and it is felt that the 16-degree tooth form, now Pametrada's standard, is the best compromise available, and there is no justification for using teeth which have less surface area, which are less flexible and which are not stronger. It is believed that all the gears proposed would run on an ordinary mineral oil without scuffing and probably the second-reduction gears of Pro-

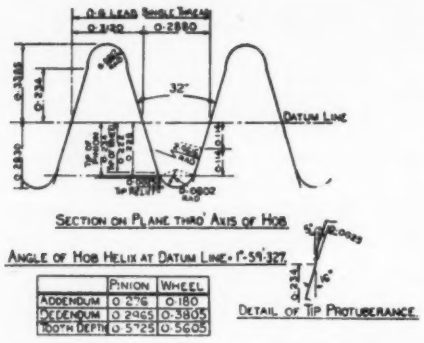

Figure 2. Tooth form used in the three studies, a 16-deg. pressure angle and 2.4 module are employed.

posals "A" and "B" are the ones which have the lowest factor of safety. At the present time, however, all the major oil companies have available satisfactory extreme pressure lubricants.

TOOTH LOADING

Surface loading has been indicated by the factor K, as defined in Lloyd's Rules. The values adopted for the En.26/En.9 material combination, namely, 100 for the first-reduction gears and 90 for the second-reduction, are relatively high by normal merchant-ship standards, but have in fact already been used with success in certain applications.

The values adopted for the hardened gears in EN.36/En.24, namely 275 for tandem first-reduction gears and 250 for dual-tandem first-reduction gears, are thought to be higher than have previously been used for merchant-ship main propulsion but the test results recorded by Newman suggest that these figures are conservative. It may be added that the hardened gears proposed are not larger than those which have been tested, so there is no reason to expect any disappointing results due to size effect.

FACE-WIDTH TO DIAMETER RATIO

The ratio of face-width to diameter for the hardened first-reduction gears of Proposal 'B" has been reduced, compared with that used for the softer gears of Proposal "A" which is in line with conventional practice. There are two reasons for this, the first being to reduce the bending deflection on these highly loaded pinions, and the second is to enable journal bearings to be provided having a length-to-diameter ratio of less than one and a specific loading under 300 p.s.i.

In Proposal "C" the face-to-diameter ratio for the H.P. first-reduction pinion is relatively high, but in this dual-tandem arrangement this pinion has been located with its axis in the same plane as that of its mating wheels, and under these circumstances there is no bending moment applied to the pinion. The pinion is, however, subject to distortion due to twisting and over the length of the forward helix the calculated displacement at the pitch circle is of the order of 0.005 in. The barrelling cam provided on pinion grinders in common use in this country is so simple that in practice any hardened pinions would be given a small amount of correction where the total calculated deflection was greater than about 0.003 in.

LOCATION OF PRIMARY TRAIN

Until recently it has been the practice to fit a sliding coupling between the quill shaft and the second-reduction pinion so that it was necessary to provide a thrust bearing on the first-reduction wheel for axial location. The latest practice recommended by Pametrada for tandem-articulated gear trains is for the quill shaft assembly to be solidly bolted both to the first-reduction wheel shaft and the second-reduction pinion. If double-helical gearing is used the whole train of gears is then located by the main thrust block and no other thrust bearings are required (Figure 3). With dual-tandem drive, however, there may be a requirement for one first-reduction wheel to move in relation to the other and it is therefore proposed that in each dual train one first-reduction wheel should be located by a solid bolted coupling as indicated above. The other wheel would be bolted to its quill shaft but a sliding coupling would be fitted between the quill shaft and the second-reduction pinion. This is indicated in Figure 4. In fact this sliding coupling may not be absolutely necessary for operational reasons but its use will aid manufacture by obviating the requirements for very precise control of the axial spacing of the helix apices for each first-reduction wheel and the second-reduction pinion assembly.

EVALUATION OF DESIGNS

All three proposals have main wheels of substantially the same diameter. Around 165 in. p.c.d. has been selected as the largest readily obtainable at the present time. It could be argued that a larger main wheel in Proposal "A" would give it a more balanced appearance and that a small main wheel could have been used for Proposal "C". There are objections to both these proposals, however, as will be seen later, and on the whole it was felt that to maintain the main wheel at the same diameter throughout rather assisted comparisons.

Before considering the merits of these designs individually it is essential to have in mind an idea of the weight and cost of each proposal. The estimated weights and relative prices of the three proposals are as follows:—

Proposal	Weight	Price Index
"A"	102 tons	100
"B"	95.1 tons	98
"C"	71.7 tons	98.5

Allowance for errors in estimating might well deprive the price differentials from having any particular significance in themselves. The potential merits

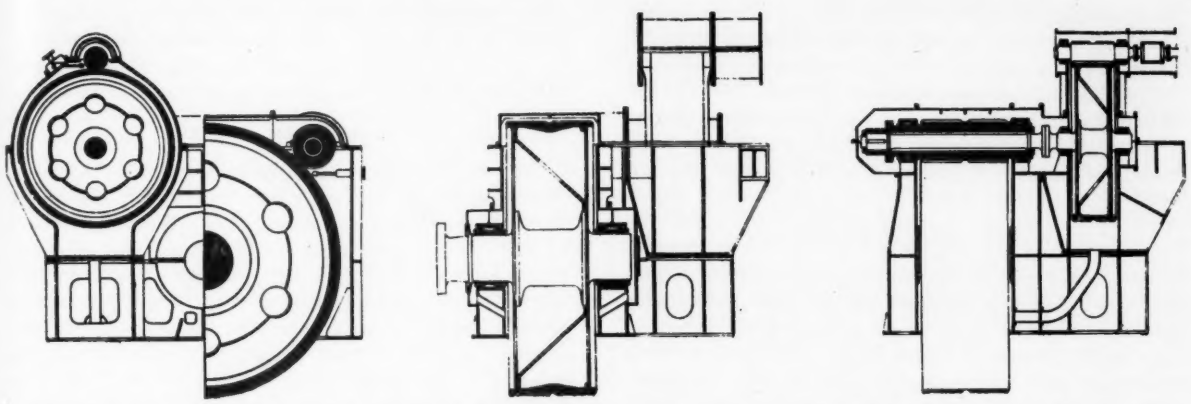

Figure 3. Single articulated train (proposal "A") with large and heavy primary gearwheels and secondary pinions, solid-coupled secondary shafts and all gears located by separate main thrust.

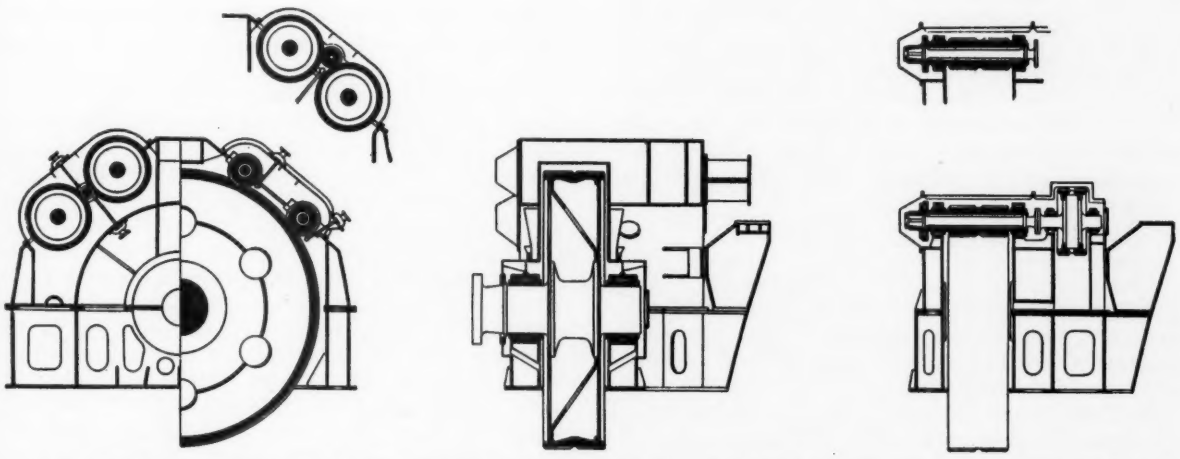

Figure 4. Dual tandem-articulated train (proposal "C"), small h.p. primary pinion in same cross axis as gears, relieving it of bending deflection. Also shown is the alternative sliding coupling for the secondary shaft.

of hardened and ground gearing have long been recognized but in the past it has been the practice to weigh these against a belief that there would be a cost penalty, but production has now been developed to the stage when designs incorporating hardened and ground gear elements can be put forward for consideration on their merits alone.

PROPOSAL "A"

This may be described as a development of the design which has become standard in tanker practice, and the general arangement is indicated in Figure 3. The materials chosen, namely, En.26 and En.9 have not been so widely used as En.25/En.8, but their higher carbon content can be expected to give superior wear resistance. The tooth loadings are, nevertheless, very high, and for the second-reduction gears would necessitate the adoption of a pitch of 0.9 in. which is larger than has previously been used with complete success. Apart from the very high tooth loading resulting from the use of a K factor of 90 with pinions of 24¾ in. p.c.d. these very large and heavy pinions are most undesirable from the production standpoint because their mass makes them difficult to set and control on the hobbing machine. With this in mind the author some years ago adopted an arbitrary rule that the limiting size for pinions should be 24 in. p.c.d. by 48 in. working face and it is still felt that larger pinions are not to be recommended.

Turning now to the first-reduction units the pitch line speed at 303 ft./sec. is exceptionally high and at 95½ in. diameter the wheels are exceptionally large and give the design an unbalanced appearance. Only the use of a higher K factor can reduce both these figures, but for the materials specified this cannot

be recommended. To sum up, gearing of this design could be made and would probably operate satisfactorily, but its capacity for development for higher torques must be very limited indeed. The torque figure for the output shaft is 15.3×10^6 lb. in. and at around this figure, or, in the author's view a little sooner, a change should be made in design conception.

PROPOSAL "B"

The major objections to Proposal "A" lie in the size and loading of the second-reduction pinions and the size and high pitch line speed of the first-reduction gears. Proposal "B" retains the same second-reduction gear elements as Proposal "A" but hardened and ground first-reduction units have been substituted to some advantage including a reduction in weight of 6.9 tons and a modest reduction in cost. The pitch line speed of the first-reduction gears has been reduced to a conservative 234 ft. per sec. and the design gives a better balanced appearance. The wheels at 74 in. p.c.d. are still fairly large but hardening them by induction heating would not present any significant problems. This proposal must be considered superior to Proposal "A," but the second-reduction units limit its acceptability for this torque and in this respect its capacity for development is very limited also.

PROPOSAL "C"

This proposal is designed to allow the use of second-reduction pinions well inside acceptable limits and carrying tooth loadings which experience would suggest are conservative. This is achieved by using a dual-tandem arrangement, the first-reduction gears being hardened and ground. The cost is estimated as between that of Proposal "A" and Proposal "B" but this is hardly as significant as a saving in weight of 30.3 tons compared with Proposal "A." The general arrangement is indicated in Figure 4. The H.P. first-reduction pinion is located with its axis in the same plane as those of its mating wheels and thus has no bending deflection, under which circumstances a tooth loading of 1,442 lb./in. of face width giving a K factor of 250 seems reasonable enough. The L.P. pinion is a little offset to increase the L.P. turbine height but the face-to-diameter ratio is less than 1.2 and the K factor only 165. In the author's view this design could be detailed and built to provide a set of gears inherently more reliable than those indicated in the other proposals and, having the added advantage of saving in weight, it must stand technically well ahead of them.

Looking forward, there would be no difficulty in developing this design up to say 25×10^6 lb. in. torque or alternatively around 22,000 h.p. from a single input shaft if required. It is perhaps worth noting also that the hardened gears are within the capacity of available nitriding plant and also that only a small reduction in H.P. turbine speed is necessary to reduce the primary wheels to a size which can be ground on the pinion grinders of which several are available within the marine industry. This, then, is the recommended design for the immediate future.

DUAL-TANDEM GEARING

Dual-tandem gearing is the type of gearing which has been considered orthodox in the U.S. Navy for over twenty years and in the Royal Navy for over a decade. It has not been widely used in merchant ships, however, though examples are found in a number of cross channel vessels, the *United States* and quite recently in the Norwegian tanker *Rein*. At the present time, however, there are still many people who will not accept dual-tandem drive: but it is suggested that this is based more on prejudice than knowledge of unsatisfactory performance of gearing due to that feature.

NON-VERNIER PRINCIPLE

In considering dual-tandem gearing arrangements, fears are often expressed that there will be serious difficulty if the locked train is disturbed and incorrectly repositioned. In order to safeguard against this possibility the gears indicated above have been designed on what has been designated "the non-vernier principle." It is a well known artifice in dual-tandem gear design to arrange the tooth numbers in the first-reduction wheel, the second-reduction pinion and the quill shaft coupling in such a way that a vernier effect is obtained by assembling them in different relative positions, and this has often been used as a means of setting the two gear trains to take equal torque. In practice, however, it has always been found easier and more practicable to mark off one set of coupling holes under torque and finally ream for the fitted bolts also in this condition. The vernier arrangements are then quite unnecessary and a virtue may be made of their elimination.

In Proposal "C", there are 60 teeth in the second-reduction pinions and 180 teeth in the first-reduction wheels. There would be 60 teeth in the one sliding coupling fitted to each dual train, and 15 bolts in each flanged coupling. The two keys in the quill shaft would be of different widths allowing assembly in one position only. Considering the train having a sliding coupling, then maldistribution of torque could be caused by:

(a) Lifting the wheel, quill shaft, coupling and pinion as one unit and replacing as a unit in a position other than the original.

(b) Dismantling the sliding coupling and reassembling with the internal and external teeth in different relative positions.

(c) Removing the bolts from either flanged couplings and reassembling with the flanges in different relative angular positions.

The effect on tooth loading resulting from (a) would be limited to that due to difference in cumula-

tive pitch error between the wheel and pinion. This could easily be held to 20 sec. of arc and as the twist on the quill shaft at full power is about 54 minutes the maximum maldistribution due to this effect would be 0.6 per cent. If it is assumed that condition (b) applies as well then, at most, a further 20 sec. of error would be superimposed giving a maximum maldistribution of 1.2 per cent, on the assumption that the maximum errors are phased to the worst advantage. With regard to (c), it is possible to devise means of ensuring unipositional assembly, but it is probably true to say that if the fitted bolts can be replaced with the flanges in more than one angular position then the accuracy of pitching of the bolt holes must be such as not significantly to affect the torque distribution.

To sum up, it seems reasonable to say that, if dual-tandem gears are made incorporating the non-vernier principle, carelessness in their reassembly will not lead to disaster attributable to the dual-tandem feature, and it is felt that this solution is an important step in furthering their general acceptance.

ARRANGEMENT IN THE SHIP

In discussions on the possibility of using dual-tandem gearing it has been said that the saving in weight due to adopting this arrangement is more than offset by the necessity for building higher seatings in the ship because it not possible to arrange the condenser underneath the L.P. turbine unless the shaft height is raised. This is not the case. In Figure 5 is shown a ship arrangement including gearing to Proposal "A" and Figure 6 shows the same modified to include gearing to Proposal "C." In these arrangements the tank top is shown 6 ft. above the base line and the main line shafting 15 ft. above the base line without rake. In practice the shaft might well be somewhat higher, but certainly it will not be lower. In both arrangements the position of the forward seating is the same as is the position of the gear box output coupling. Both condensers are designed for the same duty, namely, 28.5 in. vacuum, steam quantity 130,000 lb./hr., circulating water quantity 18,500 gal, per min. at 75°F. The condenser surface is 22,500 sq. ft., two-pass with 7,720 tubes, ¾ in. o.d. by 18 l.s.g., the length between tube plates being 14 ft. 10 in. The dimensions of the tube plate as shown in Figure 6 have been submitted to the condenser designers (independent of the author's company) and approved by them. The arrangement showing the position of the extraction pump has been approved by the pump makers. As a matter of incidental interest, the whole arrangement is very similar to that adopted for a group of large passenger vessels which have proved entirely satisfactory in service.

This seems effectively to demonstrate that dual-tandem gearing can be adopted without necessarily having to lift the line shafting. The fact that the center of gravity of the machinery has been lowered is an advantage, and while it must be admitted that the increased head room available for lifting is of no significance in a tanker, in a passenger vessel it can be a very important factor.

(a) High tensile alloy steels

At first sight it would appear that the initial development towards more highly loaded gears would be through pinions and wheels having higher tensile strengths than those specified in Proposal "A." In practice, however, all experience has shown high tensile steels in combination to be disappointing, and it is considered that, at the present time, there is no combination available superior to En.26/En.9.

(b) Case-hardened pinions with alloy steel wheels

A solution to the wear problem was found by substituting for the En.28 pinions replacements made in En.39 case-hardened and ground. This enabled the last gear set of the same dimensional design to operate very successfully, and as a result of that experience it was suggested that K factors as high as 150 would be acceptable for this type of combination. The possibility of using this combination in the first-reduction gears has been considered, but it has been strongly felt that the combination of two surface-hardened gears operating at a K factor of 250 to 275, was a far safer proposition, than operating the case-hardened pinion against an alloy steel wheel at a K factor of 150 and as there was no difficulty in making induction-hardened and ground wheels this was naturally preferred. Whether, in truth, a K factor as high as 150 is acceptable on any alloy steel even though mated with a hardened and ground pinion is debatable, particularly if the wheel is large and has to be air-hardened. If the gears are made to operate at a K factor very much below this figure they become economically unattractive due to the fact that

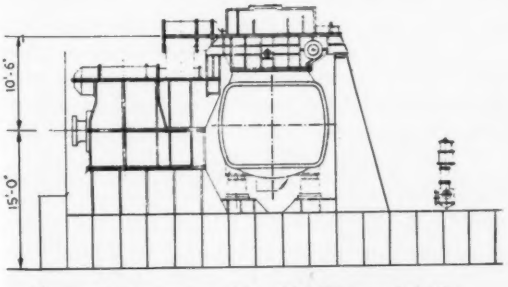

Figure 5. Arrangement in ship (Proposal "A").

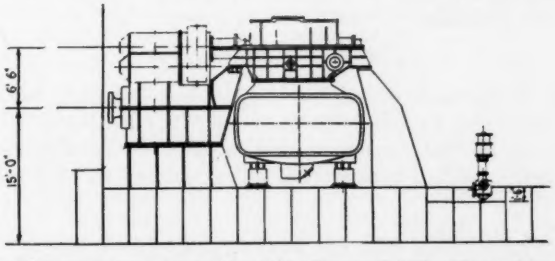

Figure 6. Arrangement in ship (Proposal "C"). The turbine center lines are some 4 ft. lower without alteration of shaft height or condenser performance.

alloy steels are likely to cost around 30 per cent more than plain carbon steels.

This latter point is important in relation to the possibility of using this type of combination for the second-reduction gearing, but in addition, to replace the second-reduction pinions of Proposals "A" or "B" by hardened ones would require two helices each about 20 in. diameter by 20 in. face width to give a K factor around 130 and a one-piece pinion of this size cannot be ground on the machines commonly in use in this country.

(c) Hardened main wheels

There is not at present available in this country equipment suitable for hardening main wheels in the 10 to 12 ft. range that would be required for this sort of application. There is no fundamental difficulty in developing induction-hardening equipment for this duty, and such gears could be ground subject to using either a single-helical gear or alternatively a larger gap than is desirable.

(d) Nitrided gears

Nitriding equipment is available in this country up to a capacity of about 40 in. At the present time a few tests on a 36 in. diameter wheel have been completed and the initial test results are very promising indeed. Subject to further test results being satisfactory it is possible that the nitriding process could be substituted for induction hardening, or case hardening as applicable.

(e) Conventional materials (En.26/En.9) with dual tandem drive

A proposal incorporating the above would provide a solution to the specific problem considered here which, in the author's opinion, is superior to Proposals "A" or "B." Using the same second-reduction units as Proposal "C" and a K factor of 90 for the first-reduction gears, the wheel diameters would be about 55 in. As 60 in. diameter is the largest which can conveniently be used in conjunction with a main wheel of 165 in. diameter the development possibilities are limited, and also this proposal would cost more than the conventional Proposal "A," whereas Proposal "C" costs less. As the inclusion of hardened first-reduction gears produces a neater, lighter and less costly unit with greater development possibilities, Proposal "C' had to be preferred.

ECONOMIC CONSIDERATIONS

In the table of relative weights and costs it is indicated that Proposal "B" is cheaper than Proposal "A" because the hardened and ground first-reduction gears are less expensive than the hobbed and shaved first-reduction gears of Proposal "A." Hardening and grinding costs more than shaving, and it would be misleading not to make it clear that the reason for the decrease in total cost is that the tooth loadings have been selected at a value high enough to ensure that the saving in weight and the corresponding saving in material costs is sufficient to offset the extra cost of hardening and grinding. It follows that if hardened and ground gearing is proposed with only a nominal increase in loading the weight saving would be less and the hardened and ground gears would be more expensive than their hobbed and shaved counterparts.

Also it should be pointed out that the relative prices stated apply in this instance to gearing in which the pinions are carburized, quench-hardened, and ground while the wheels are induction-hardened and ground. For the relatively small pinions referred to there is little difference in cost attributable to hardening method; but the cost for case-hardened and ground wheels would be higher than for wheels hardened by induction heating prior to grinding. It would not be practicable to make the 74 in. wheels of Proposal "B" each with its two separate rims except by using induction hardening or nitriding which, it is expected should be competitive against induction hardening.

In all the previous discussion no account has been taken of the value of the saving in weight to the shipowner. The precise importance of this factor varies with applications but in the case of a tanker it can be argued that for a given hull form a saving of 30 tons in weight, as indicated by Proposal "C" over Proposal "A" is 30 tons extra deadweight capacity available to the owner, and similar considerations apply to cargo vessels. If deadweight capacity is reckoned to be worth 30s. per month per ton than 30 tons weight saved is worth £540 p.a. as extra earning capacity. Adapting the seven-year rule proposed by Bonny,* the cash equivalent of 30 tons saved might be £3,780.

For the very high torques, which are the subject of this paper, a twin-turbine arrangement using dual-tandem gearing having hardened first-reduction units is particularly attractive, showing a considerable saving in weight and having factors of safety believed to be not less than those effective in conventional gearing. It is proposed at this stage to harden only relatively small gears in which field production has been developed to the point where hardened gears conservatively loaded in relation to full scale test experience, have become commercially attractive. If dual-drive and hardened first-reduction units are accepted, requirements for up to 25×10^6 lb. in. torque can readily be met.

*Bonny, A. D., "Modern Marine Steam-Turbine Feed Systems." *N.E.C. Inst. Trans.*, 1957.

JOHN W. SAWYER

GAS TURBINES—DEMONSTRATED ABILITY

THE AUTHOR

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DEVELOPMENTS in gas turbines during the past ten years have brought this prime mover into positions that make it most attractive. The improvements include advances in design, metallurgy, manufacturing techniques, and materials. They have made many advanced thermodynamic concepts practical. These have resulted from combined research-development-operation experiences.

During the past several years numerous papers have been presented on the operational experiences of users of gas turbines. The field uses have definitely demonstrated the exceptional capabilities of the gas turbine in many areas. In the following pages some of the pertinent information relating to the gas turbine and its established records is summarized. It is hoped these data will be of interest and value to those who are concerned with the selection, installation, operation and maintenance of gas turbine engines.

RANGE OF APPLICATION

The mere fact that the gas turbine is now being applied in increasing numbers in a variety of fields is evidence of its proven and accepted advantages. It is not being applied just to gain experience with a new machine. Selection of the gas turbine today is due to its ability to do a better job than any other prime mover. The economy of the engine must be based on overall requirements for the application under consideration. There are many factors that must be considered in the ultimate selection. These include: first cost, fuel type and rate, cooling water needs, overhaul interval, efficiency, life requirements, ease of maintenance, depreciation, number of

operating personnel, specific weights, space requirements, operating conditions, low maintenance cost, ease of control, cold starting ability, environment, reliability and utilization.

The following fields are representative of the range of application:

a. Aviation
   1. Turboprop
   2. Turbojet
   3. Auxiliary power supply
   4. Propulsion engine starters

b. Industrial
   1. Propulsion, locomotive
   2. Power generation, central station
   3. Steel, compressor for blast furnaces
   4. Chemical process
   5. Pump drives
   6. Oil field generator
   7. Gas line pumping
   8. Road vehicles
   9. Off-road equipment

c. Marine
   1. Propulsion
   2. Generator, electrical
   3. Pump drive
   4. Air supply
   5. Starter for gas turbines
   6. Fog generator

INITIAL COST

This is certainly one factor that gets an early study in selecting an engine. Gas turbine prices were, ten years ago, high as compared to other plants. That was in the early stages of development, manufacture and operating experience. The initial costs have steadily decreased. When produced in relatively large lots the cost should be equal to or less than the reciprocating internal combustion engine or steam turbine-boiler plant.

A prime mover for a 6200 KW mobile power plant was studied. The following relative cost for the complete plant was determined (1):

Prime Mover	Cost of Complete Plant—Percent
Diesel	150
Steam turbine-boiler	130
Gas turbine	100

From these cost comparisons the gas turbine plant was selected in preference to either diesel or steam turbine.

Marine power plants utilizing high horsepower gas turbines for propulsion have not been produced in quantities. Therefore it is not feasible to quote engine costs based on extensive procurements.

However, numerous studies have been conducted which show the gas turbine to be highly competitive. It has been reported (2) that gas turbine machinery cost will not exceed 1.16 that of heavy oil machinery, with steam turbine at 1.09. It is believed that costs should be materially reduced by new and improved manufacturing methods and materials. A second study (3) indicates that the installed cost of a marine gas turbine plant will be less than a steam turbine plant in sizes generally used in merchant ships.

The installed cost of an unattended, remote controlled pumping unit, located in a desert, including 5000 HP gas turbines with all controls and portable shop installations is actually one-sixth that of a typical diesel station with its vast array of supporting facilities and personnel (4).

A recent comparison of available gas turbines, gasoline and diesel engines shows the initial cost of these prime movers on a dollar per horsepower basis (5). This comparison, which is reproduced with the special permission of *Business Week*, is as follows:

GAS TURBINES

Manufacturer	Name	Hp.	Lb./hp.	Cost/hp.	Fuel consumption per hp. hour
Allison	GMT-305	225	2.65		.55
AiResearch Mfg. Co.		30-1000	.40	$18,000-$25,000*	.65
Boeing	502-10C	240	1.36	$62.5	.7-1.0
General Electric	T-58	800	.34		.69
Clark Bros.	Mark TA	1220	10.	$80-$110	.91
Continental	TC 106	160 (Air hp.)			
Lycoming	T-53	700	.69	$30	.75
Solar	Jupiter	500	1.1	$100	.95
	Saturn	1000	.75	$50	.65

*Total Price

THEIR CHIEF RIVALS

Chrysler Marine V-8 (Gasoline)	Imperial special	225	4.7	$11.10	.61
Aircraft Type (Gasoline)	Allison V-12	1250	.995		.52
Diesels		20-500	6-10	$16-$30	.4-.55

MAINTENANCE COSTS

The cost of maintaining an engine is an important point for consideration. If this cost is high, a particular machine may not be suitable for a given application. A number of gas turbine maintenance cost examples will be presented. Some of these will be compared with the maintenance cost of other prime movers.

The Shell Company's experience with reciprocating engines and gas turbines, all for generation of electrical power for oil fields in Venezuela, has provided some interesting information (6). A central power station had the following engines installed for power generation:

a. 6 dual-fuel internal combustion reciprocating engines, each 500 KW
b. 2 internal combusion reciprocating engines, each 950 KW
c. 1 gas turbine, (Metropolitan Vickers) 1750 KW
d. 1 gas turbine, (Gasturbine Maat, N.V.) 2000 KW
e. 2 gas turbines, (General Electric) 5000 KW

It is of interest to note that the maintenance cost of the piston engine is about 14 percent greater than those of the 5000 KW gas turbines. Operating costs for the piston engine are approximately 94 percent greater than those of the 5000 KW gas turbines. A comparison of the total operating and maintenance costs indicates that the reciprocating engines cost about 91 percent more than the gas turbines. A tabulation of the comparative cost on a KW-hr basis is as follows:

Engine	Cost-Pence/KW-hr Operation	Maintenance	Operation and Maintenance
Gas Turbine	0.196	0.142	0.338
Piston Engine	0.381	0.262	0.643

Maintenance cost figures on several types of prime movers have been released. These show actual maintenance cost per KW-hr as follows (7):

Engine	Cost U.S. cents/KW-hr
a. 1200 HP gas turbine on *Auris*	0.06
b. Brown-Boveri gas turbine (based on 100,000 hour service)	0.023
c. Diesels (British Diesel Engine Users Association)	0.30
d. Steam turbines (without boilers—British Electricity Authority)	0.049

The experience on mountain runs of the Union Pacific Railroad with gas turbines, diesels and steam engines is illustrated by the following tabulation (8):

Expense Item	September 1954 Costs in cents/1000 gross ton mile Steam	Diesel	Gas Turbine
Repairs	27.44	16.56	14.45
Engine house	14.89	3.66	2.24
Fuel	54.99	20.12	22.23
Lubricants	1.47	1.40	.47
Other supplies	5.65	.16	.04
Enginemen	18.28	18.79	14.22
Trainmen	22.42	23.34	15.54
Total	145.14	84.03	69.19

Overhaul costs, on the Dart turboprop engines operated by Capital Airlines are $3.51 per engine flight hour (9). These engines had accumulated some 300,220 flight hours prior to December 1957. At that time the engine hours per failure on the Dart 506 gas turbine were 21,444. Experience with the Dart 510 indicated some 115,000 engine hours per failure. The following relates to overhaul costs, material and labor, on these engines:

a. Hours between overhauls (CAA approved) 1500
b. Average bare engine overhaul (labor) $1150.00
c. Average bare engine overhaul (man-hours) 490
d. Average bare engine overhaul material cost.....$3850.00
e. Overhaul cost per flight hour .....$ 3.51

Operating experience, over a period of some 34,000 hours, with a 5400 KW gas turbine at Luxembourg, showed a maintenance cost of 0.0695 US Mills/KW-hr (10).

The General Electric 6600-hp gas turbine in the *John Sergeant* during its operation to date, representing some two years during which she sailed over 94,000 nautical miles with 6567 hours operation, has shown superiority over a marine diesel prime mover due to freedom from maintenance (11).

AVAILABILITY

The intensive development and rapidly expanding use of the gas turbine account for its enviable record of availability. The factor of availability has been defined as follows (12):

$$\text{Availability factor} = \frac{\text{Installed hours} - (\text{Forced outage plus Maintenance) hr.} \times 100}{\text{Installed hours}}$$

Two 5000 KW gas turbine sets providing electrical power for oil fields at La Concepcion, Venezuela have achieved extremely good availability factors (6). One plant with a total running time of 9,564 hours, as of April 1957, had an availability of 89.4 percent. A second unit in the same service with some 13,408 hours running time, as of April 1957, showed an availability of 95.2 percent.

A 5400 KW gas turbine plant, normally operating on blast furnace gas but with provisions for use of liquid fuel, had a total running time, as of June 1956, of 33,362 hours. During this time the availability factor was greater than 86 percent (10).

In one power generating gas turbine set with over 27,000 hours operation the availability has been 89.4 percent (13).

An analysis of a number of base load gas turbines, with use factors greater than 96 percent, revealed that the average availability was 98.17 percent. These units had operated a total of 68,890 hours (12).

A gas turbine for emergency power supply, 300 KW generator, on the USS *Gyatt* has maintained an availability of practically 100 percent during the period of March 1957 to April 1958. In this time the set was down for a very short time due to one failure to start, caused by a low battery, and one engine shutdown. A total of 135 successful starts were made.

Maintenance time on this set has been very minor. Based on the above definition this emergency set has had approximately 100 percent availability.

OVERHAUL INTERVAL

The hours of operation between overhauls of gas turbines vary over an exceptionally wide range. These overhaul intervals depend on many factors including: type of service, utilization, reliability, availability, fuel, materials and design. The term "overhaul interval" is preferred to the one "overhaul life" because the latter suggests that at the end of a given period the engine is, for all practical use, to be torn down and have all parts replaced. This is not true by any means. An overhaul on a 500 HP marine gas turbine indicates an overhaul cost of 5 to 10 percent of initial engine cost as compared to reciprocating engine overhaul cost of 30 to 40 percent of new engine cost (14).

A tabulation of gas turbines suitable for marine use listing some 63 engines by eighteen manufacturers shows overhaul intervals from 300 to 100,000 hours. These turbines range from 50 to 30,400 horsepower (15).

It is not unusual for the large industrial type gas turbines to operate many thousands of hours without inspection, let alone overhaul. For examples, the following operating experience is cited:

a. 5000 KW Brown-Boveri gas turbine at Dharan ran for 12,168 hours prior to inspection (10).
b. 5000 KW Brown-Boveri gas turbine used by Arabian Oil Company operated over 15,000 hours prior to inspection (10).
c. 6600 HP General Electric gas turbine propulsion plant on GTV *John Sergeant* operated 6,567 hours and 94,000 nautical miles without any maintenance (11).
d. 5000 KW General Electric gas turbine in service with Oklahoma Gas and Electric Company was given an inspection after almost 30,000 hours of operation (16).

Small gas turbines in the 50 to 1000 HP range are on relatively long overhaul intervals. Turbines in marine service have shown remarkably long operating periods. Some engines in this class have experience as follows:

a. 500 HP Solar propulsion turbine operated some 800 hours at sea, driving a 40 ft. boat over 16,000 miles at speeds in excess of 25 knots. Most operation was at 97 percent of rated speed. Engine starts totaled 1225. No overhaul has been required up to April 1958 (17).
b. 160 HP Boeing generator drive engines have a 500 hour overhaul. Some 184 engines are in use by the U.S. Navy (18). One engine has operated on laboratory test for 2,500 hours without overhaul. Some minor parts were replaced during this test (19).

Aircraft experience with propulsion gas turbines has been very good. Engine overhaul interval is steadily increasing. Commercial airline service has shown that maintenance cost for reciprocating engines per engine flight hour is more than 200 percent of the maintenance cost of gas turbines. Data presented on the Dart gas turbine, powering Capital Airline Viscounts, shows time between overhauls of 1,500 hours, prior to December 1957 (9). It is understood that other gas turbines in commercial service also have long overhaul intervals. The time between overhauls on these engines is *steadily increasing.*

The Bristol Proteus 705 aircraft engine had an overhaul interval of 500 hours when it was first placed in passenger service. In less than two years this overhaul interval had been increased to 2000 hours (21).

RELIABILITY

Dependability of a prime mover is of paramount importance. The user must know whether a machine will have a satisfactory reliability factor prior to its selection. The factor of reliability has been defined as (12):

$$\text{Reliability factor} = \frac{(\text{Installed hours} - \text{Forced outage hours}) \times 100}{\text{Installed hours}}$$

The gas turbine has well demonstrated its reliability in aviation, industrial, transportation and marine fields. The base load machines have reliability such that they have been accepted by public utilities for power generation.

A 5000 KW gas turbine driven generator supplying power at an oil field location (6) has been installed for about 24,000 hours. During this period the forced outage was 10 hours. The reliability of this unit has exceeded 99.9 percent. At the same location a second gas turbine has been installed for some 21,600 hours. This unit has experienced a forced outage of 20 hours and has a reliability of at least 99.9 percent.

In a gas turbine generator set supplying electric power for a utility company the unit has been down for 34 hours due to forced outages. The installed time for this engine was 31,542 hours. This gives a reliability factor of 99.85 percent (13).

UTILIZATION LEVEL

The extent to which a gas turbine is in actual use varies with the demand. In emergency type duty the ratio of hours fired to the hours installed, defined as the "use factor" (12), can be extremely low. A unit that is in operation twelve hours out of each day installed would develop a use factor of 50 percent.

The gas turbine has met the requirements for prime movers throughout the use factor range. It is serving for emergency power, transportation including railway, ship and aircraft and also for base load plants in utility service.

It is particularly significant to note that the gas turbine has been operating in the very high use factor level for a number of years. These turbines are of the industrial types. The Union Pacific's gas turbine driven locomotives have a use factor, for August 1956, of 58.2, averaged over 25 engines (20). The locomotives averaged 432 fired hours. During this period the locomotive fleet powered by gas turbines averaged 12,026 miles each. This was higher than any other type engine working in the same

area. The gas turbine trains had an average speed of 34.95 miles per hour. The diesel electric trains had a speed of only 28.95 miles per hour.

A 5400 KW gas turbine at the Dudelange steelworks in Luxembourg serves for generation of electric power and also can supply bleed air for blast furnaces. This set had, as of June 30, 1956 operated 33,362 hours with a plant utilization factor of about 75 percent (10).

Three base load machines have been reported with a use factor of 96.32 percent average (12). The total fired time for these three machines was 68,890 hours with a total of 71,550 installed hours. These machines have had an availability in excess of 98 percent with a reliability of 99.34 percent. This is certainly ample proof of the ability of the industrial type gas turbine to maintain extremely high availability and reliability in machines with use factors in excess of 96 percent.

A 5000 KW gas turbine set operating in the Pertigalete Cement Works, Venezuela operated a total of 16,088 hours out of a possible 16,128 hours. This unit has a utilization factor of 99.75 percent. The time for turbine inspection is included in this factor (10).

OPERATING PERSONNEL

Reduction of operating personnel is an attractive means of lowering operating costs. In a number of applications the gas turbine prime mover has demonstrated its advantage in this respect over reciprocating combustion engines and steam turbines.

Industrial use of gas turbines in rail service amply illustrates the fact that generally fewer personnel are required to operate the gas turbine plant. The Union Pacific (8) found its cost in cents/1000 gross ton mile for enginemen was 14.22 with gas turbine and 18.79 for diesel driven locomotives. This shows that approximately 25 percent less personnel are required for the gas turbine powered locomotive.

In the marine field the reduction in size of engine operating crews by use of the gas turbine is equally attractive. The U.S. Maritime Administration converted four Liberty ships from their original propulsion plants which were reciprocating steam engines. These ships with engine room personnel are shown in the following tabulation:

Ship	Propulsion Plant	Number Engine Personnel	Relative Size Engine Crew
John Sergeant	Gas Turbine	12	1.00
Thomas Nelson	Diesel	14	1.16
Benjamin Chew	Steam Turbine	16	1.33
William Patterson	Free Piston/Gas Turbine	12	1.00

The above ships are operated by commercial companies. The engine room crew for the diesel ship is 16 percent greater than for the gas turbine, while the steam turbine engine room crew is 33 percent greater than that of the gas turbine ship. This is a most significant factor "when one considers that the reduction of one man per watch can result in a saving in operating cost comparable to an improvement of about 10 percent (in overall plant efficiency) on a cargo vessel with a propulsion plant rated at 20,000 HP (based on 5,000 operating hours per year underway and fuel costing $2.70 per barrel)"(3).

Dependability, simplicity and requirement for a relatively small number of supporting auxiliaries and services are the main reasons for the small number of operating personnel needed for a gas turbine installation. Gas turbines are ideally suited for operation by remote control. This is true of industrial as well as marine type installations. An outstanding illustration of remote control operation is the new pumping plant of the Trans-Arabian Pipe Line Company (4). This station consists of six pumping units driven by 5000 HP gas turbines. These turbines are fueled with crude oil taken directly from the pipeline. They are required to operate throughout a temperature range of 30-120°F. The radio control positions are 50 to 100 miles away from the turbines. Operation from the remote station is so simple that it even includes the addition of an aqueous solution of magnesium sulphate to the turbine fuel, which contains about 10 ppm of vanadium, to minimize turbine blade corrosion.

CONCLUSION

The gas turbine has proved its merit. Aviation, both civil and military, is rapidly converting to turbojet and turboprop engined craft. Oil field transportation and utility uses are increasing. The automotive field offers a vast range of application with improvements being made in the gas turbine efficiencies. Many experts feel that this prime mover will, in a matter of a relatively few years, be the automotive engine.

With the proven reliability, availability, low maintenance, high power weight ratio, low installation costs and many other advantages the gas turbine will certainly see a greatly accelerated rate of application in all fields.

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Mr. Sawyer has contributed generously and authoritatively to the gas turbine literature over the past six years. His treatments given from year to year have paralleled the development of the gas turbine from an engineering novelty to its present status as a useful, economical and reliable power source.

In past years Sawyer felt that one of his aims was to search out especially suitable gas turbine applications and demonstrate carefully the details of this suitability. It is significant now to notice Sawyer's present thesis that gas turbines in a host of places, from small powers to large have overtaken piston and steam power sources from many standpoints including first cost, maintenance, operation, reliability and use rates. And the end is not in sight.

In fact, the gas turbine is at the starting end of its growth curve, a curve that must surely show over the next decade great strides in all the departments pointed out by Sawyer in this paper.

"U. S. NAVAL INSTITUTE PROCEEDINGS"

THE ST. LAWRENCE SEAWAY: NATIONAL DEFENSE ASPECTS

ACKNOWLEDGEMENT

The author of this article is Harry C. Brockel, Municipal Port Director of the City of Milwaukee, and a member of the five-man advisory board of the St. Lawrence Seaway Development Corporation. Reprinted from the May 1959 edition of U.S. Naval Institute "Proceedings." Copyright 1959 by U.S. Naval Institute.

INTRODUCTION

On the banks of the storied St. Lawrence River, President Eisenhower, Her Majesty Queen Elizabeth II, an array of dignitaries, and citizens of several nations will assemble next month* for the official dedication of one of the world's most significant waterway projects.

After 35 years of regional struggle and congressional debate, the Seaway was finally authorized by the United States Congress in May, 1954. President Eisenhower signed the bill immediately, and within a few weeks one of the greatest engineering tasks in the history of the world was under way. It took only 4½ years—from late 1954 until early 1959—for the engineering genius of Canada and the United States to bring into being the second largest power project in the world and a new waterway which will make the Great Lakes into "The Eighth Sea" or "The New Mediterranean."

When opened to deep-draft ships the St. Lawrence Seaway will consist of a 2,400 mile waterway system extending from the Atlantic Ocean through the St. Lawrence River and the Great Lakes to the headwaters of the Lakes. Although a joint project was contemplated for many years, the legislation finally enacted by Canada and the United States made a simple and logical division of the work, with each country building the structures and improving the channels within its own territory.

The American share of the work consisted of dredging deep channels in the 68 miles of the Thousand Islands section of the river and of constructing two great locks and auxiliary facilities in the International Rapids section near Massena, New York.

Under authorization by Parliament, Canada constructed four locks in her territorial waters between Montreal and Cornwall, Ontario. The Canadian construction is in the Lachine, Soulanges, and Beauharnois sections of the St. Lawrence, with locks and canals to by-pass the turbulent waters of several great rapids. Canada also has built a fifth lock and canal at Iroquois, Ontario, west of the American locks. She will also deepen the approaches to the Welland Canal, the great ship canal which takes shipping around Niagara Falls and circumvents the 326-foot difference in elevation between Lakes Erie and Ontario.

Two other significant navigation developments are under way, under United States direction as a separate but related project. The U. S. Corps of Engineers is deepening the connecting channels of the Great Lakes from the present 21 and 25-foot depths to the new project depth of 27 feet.

Obviously a new 27-foot system of navigation through the St. Lawrence River and the Detroit River and throughout the Great Lakes region would be frustrated unless ships loaded to that draft could find terminal ports capable of receiving them and handling their cargoes. In a third important pro-

*Written in May, 1959

THOUSAND ISLANDS SECTION
68 MILES
INTERNATIONAL RAPIDS SECTION
44 MILES
LAKE ST. FRANCIS SECTION
30 MILES
SOULANGES SECTION
16 MILES
LACHINE SECTION
31 MILES
MAP OF
GREAT LAKES - SAINT LAWRENCE SEAWAY PROJECTS
ISSUED BY
SAINT LAWRENCE SEAWAY DEVELOPMENT CORPORATION
LEWIS G. CASTLE Administrator
M. W. OETTERSHAGEN Deputy Administrator
Construction of the Seaway Project, Lake Erie to Montreal, is being performed as indicated above by The Saint Lawrence Seaway Development Corporation of the United States and The St. Lawrence Seaway Authority of Canada
SAILING DISTANCES IN MILES
GREAT LAKES
SEAWAY PROFILE
GREAT LAKES - SEAWAY PROFILE
ONTARIO
QUEBEC
LABRADOR
NEWFOUNDLAND
NOVA SCOTIA
N.B.
ME.
N.H.
VT.
MASS.
CONN. R.
N.J.
NEW YORK
PENNA.
OHIO
MICH.
IND.
ILL.
WIS.
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ERIE
LAKE ONTARIO
SAINT LAWRENCE SEAWAY
WELLAND CANAL
SEVEN ISLANDS
ANTICOSTI ISLE
QUEBEC
THREE RIVERS
MONTREAL
KINGSTON
CAPE VINCENT
OSWEGO
ROCHESTER
BUFFALO
TORONTO
HAMILTON
SARNIA
PORT HURON
DETROIT
TOLEDO
SANDUSKY
CLEVELAND
ASHTABULA
ERIE
SAULT STE. MARIE
MILWAUKEE
CHICAGO
GARY
MILWAUKEE
PORT ARTHUR
FORT WILLIAM
DULUTH
SUPERIOR
ESCANABA
MANISTIQUE
MUSKEGON
PRESCOTT
OGDENSBURG
MASSENA
CORNWALL
IROQUOIS
NORTH BAY
ALBANY
NOSHIN
SCALE OF MILES

gram, the Congress has authorized the Corps of Engineers to survey the economic needs of the various lake ports with respect to the new era of deep-draft lake and ocean shipping, and these studies are well advanced. The timetables are: St. Lawrence Seaway completion and opening this spring, completion of the Great Lakes connecting channels improvements by 1963; and progress on the deepening of lake harbors as rapidly as Congressional budget action is taken and the necessary contracts can be executed.

"The New Look" on the Great Lakes embraces not only the tremendous engineering works involved in the Seaway project and the building of an enormous hydroelectric structure, but the engineering marvel of the new Straits of Mackinac Bridge and a multimillion dollar program of new port structures in the lake ports which expect to be the principal terminals for the many new ocean lines now in operation or projected for the Great Lakes. The largest Great Lakes bulk freighters will be able to move freely between lake ports and tidewater. An estimated 80 per cent of the world shipping fleet will find the Great Lakes accessible as a new world trade route. The small ocean ships and small "Canalers" which now link the Great Lakes and Montreal may linger briefly, but the inexorable facts of transportation will no doubt see them quickly replaced by fast, deep, large-capacity ships. One example of the attraction of the new project to shipping will be that an estimated two days—perhaps more—will be chopped off transit time between Montreal and the Great Lakes, with wide and deep canal sections replacing present shoestring canals and with seven tremendous locks replacing 21 obsolete small locks into which ships must be almost literally shoehorned, at great cost in time and frustration to vessel masters.

THE SEAWAY AND NATIONAL DEFENSE

The military potentialities and the national defense aspects of the Seaway have been a major consideration in the prolonged national debate on the project and in international discussion of it. For example, during the defense mobilization, preceding World War II, President Roosevelt sent several special messages to the Congress urging immediate construction of the Seaway to add to the national arsenal for defense. On October 17, 1940, President Roosevelt said, "The development . . . of the Seaway should be undertaken at the earliest possible . . . to meet the continuing power requirements of the defense program in essential centers of war material production. The potential power at this site is best adapted to meet the requirements of expansion in certain essential defense industries including aluminum, magnesium, ferro-alloys, chemicals, etc. The project may be considered as an essential part of the program of continental defense."

In a special message in June, 1941, President Roosevelt said "I recommend construction of the St. Lawrence Seaway and Power Project as an integral part of the joint defense of the North American continent . . . your action will either make available or withhold 2,200,000 horsepower of low-cost electric power for the joint defense of North America. Your action . . . will either open or keep bottled up one of the greatest transportation resources ever offered to people . . . . Our defense production is a gigantic assembly line; transportation is its conveyor belt. The Seaway . . . will provide a great highway to and from important defense production areas. It will cut by more than a thousand miles the stretch of dangerous open water which must be traveled by supplies to Great Britain and Strategic North Atlantic bases. It will increase our capacity to build ships . . . The St. Lawrence Project must be expedited. No comparable power, shipbuilding and transportation facilities can be made available. . . . I know of no single project of this nature more important to this country's future in peace or war."

When he became president, Harry S. Truman similarly urged the building of the Seaway both for national expansion and to strengthen the country militarily.

As Chairman of the Joint Chiefs of Staff, and later as President, Mr. Eisenhower, with his experienced military background, became persuaded of the military merits of the project and its value to the national defense. His convictions were buttressed by a report of a special cabinet committee which he appointed to study the project from both the military and economic standpoints.

In the final historic debate in the United States Senate in 1954, borderline votes were favorably influenced by a special report by the Joint Chiefs of Staff who, just before the final Senate vote on the Seaway Bill, advised the Senate that the construction of the Seaway with United States participation would:

(1) Afford access of a relatively protected route to additional sources of high-grade iron ore, coal, lead, zinc, copper, titanium, and manganese;

(2) Assure joint control . . . as important from the national security aspect as the Seaway itself;

(3) Help in meeting the threat of submarine attack to exposed overseas shipping routes for essential materials;

(4) Assure the United States the full benefits . . . in a shorter, more protected overseas route to the British Isles and Europe for transportation of military cargo;

(5) Afford access to additional shipbuilding and repair facilities.

In view of the foregoing, the Joint Chiefs of Staff "consider the joint participation in the construction and operation of the St. Lawrence Seaway as necessary in the interests of national security."

The military minds of the United States have always been conscious of the relatively sheltered location of the St. Lawrence route, with only 2,200

miles of open ocean between the Gulf of St. Lawrence and the Channel ports, as compared to 3,300 miles via the ports of New York, Boston, or Philadelphia. The Gulf of St. Lawrence is much easier to protect against submarine attacks than are the open waters of the North Atlantic, attested to by the terrible losses in men, material, and ships suffered by North Atlantic convoys during the early years of World War II.

From the military standpoint, the Seaway will also open up the extensive shipbuilding resources of the Great Lakes area, which were used only to a minor degree in the last war. Of seventy million tons of naval and merchant shipping built in the United States during World War II, only about 2½ per cent was launched in Great Lakes harbors, because of the difficulty of getting ships to sea via the shallow draft Illinois-Mississippi route or via the extremely limited St. Lawrence route. More than 60 per cent of the total material going into the shipbuilding program, however, originated in the Great Lakes area, and these millions of tons of material—steel, gears, engines, propellers, auxiliary motors and the like—had to be transported by congested overland routes to shipbuilding centers on the seaboard. A cheaper cost for large-scale shipbuilding programs is reasonably indicated by the resources of the Great Lakes region in terms of steel production, water transportation, sheltered harbors, and large reservoirs of manpower, backed up by the machine shops of the continent which cluster on the shores of the lake region. A major report by the National Security Resources Board in 1950 strongly supported the building of the Seaway to buttress the national defense.

NATIONAL SECURITY AND IRON ORE

In modern military technology, steel productive capacity and military strength are intimately related. Excluding uniforms and food, practically everything employed by an army, a navy or an air force involves metals of infinite variety; but the military machine is basically a machine of steel, with aluminum an important secondary metal. The steel productive capacity of the United States in World War II generated veritable floods of ships, tanks, guns, planes, vehicles, and ammunition which literally overwhelmed the Axis. Steel pipelines carried the "Big Inch" across the United States to pour out a flood of petroleum products on the Eastern Seaboard which shortened the vulnerable ocean movements to Europe; and another steel pipeline powered General Patton's dash across Europe and was vital in the final destruction of the German Army.

In the years of international tension and friction since 1945, one of the reassuring factors on our side has been that the world predominance of iron and steel production was in the hands of the NATO countries; and there is now some reason for apprehension with the curve of steel production creeping up within Russia and Red China.

The events of two world wars demonstrated conclusively that industrial capacity is as mighty a weapon as armies and navies and that the nation which has an industrial plant adequate to supply and maintain land, sea, and air forces on a colossal scale is the power which must inevitably prevail in the military as well as in the economic struggle.

At the peak of the World War II effort, more than a hundred million tons of iron ore was drawn each year from the Mesabi Range, America's prime source. Domestic reserves, and especially those of Mesabi, were seriously depleted by the staggering volume of steel production required to win World War II. In modern times, the Lake Superior region has supplied about 85 per cent of the total iron ore requirements of the United States. An average of 75 to 80 per cent of national steel production comes from the Great Lakes Basin, reflecting the rich deposits of iron ore, coal, and limestone brought together at low cost by lake navigation. Starting with these facts, good cause for national concern in the matter of iron ore supply and steel production is well demonstrated by the analysis made by the National Security Resources Board in 1950, Table I.

To a large degree, the relationship of the St. Lawrence Seaway to national defense steel production and iron ore supply is told graphically by this simple analysis. With national steel productive capacity primarily in the Great Lakes Basin and with prime Mesabi ore running out, the opening of the St. Lawrence Seaway becomes the indispensable vehicle to reach the rich ore resources of Eastern Canada and of South America, Cuba, Africa, and Sweden, as well as for the movement of manganese and other vital alloys and non-ferrous minerals of top importance to the enormous industrial plant of the Great Lakes Basin.

WATER POWER AND NATIONAL DEFENSE

Another significant military aspect of the Seaway Project is the harnessing of the enormous hydroelectric power capacity of the St. Lawrence River in the International Rapids section between Massena, New York, and Cornwall, Ontario. The spectacular but dangerous Long Sault Rapids of the St. Lawrence have already disappeared from view as a result of the building of the second largest hydroelectric dam in the world. Built by the Province of Ontario and the Power Authority of the State of New York, the dam has been named in honor of two famous "Bobs," the late Robert H. Saunders, Chairman of the Hydroelectric Power Commission of Ontario (an untimely victim of an airplane crash just as his long vision of building the St. Lawrence power dam was about to be realized), and the fiery Robert Moses, oft-called by the State of New York to handle tough assignments. As Chairman of the New York State Power Authority, Moses has driven the great St. Lawrence Power Project to completion, meeting every target date.

The great new power dam harnesses the 92-foot

TABLE I—*Prospective Supply and Demand for Iron Ore Assuming A Normal Growth in Capacity and Its Full Utilization*

	Unit	1950	1955	1960	1965	1970
Probable ingot capacity	Millions of net tons	100	105	110	116	122
Total ore requirements of steel mills and foundries based on steel mills operating at 95 per cent of capacity and using 50 per cent scrap	Millions of gross tons	113	118	124	131	137
Probable maximum output of all ore producing regions other than Lake Superior	Millions of gross tons	17	17	17	18	19
Probable maximum output of Lake Superior ores exclusive of taconite concentrates	Millions of gross tons	83	80	70	50	40
Probable maximum output of taconite concentrates in terms of 51 per cent iron content	Millions of gross tons	0	3	12	22	30
Total ore production	Millions of gross tons	100	100	99	90	89
Import requirements	Millions of gross tons	13	18	25	41	48

NOTE: This table reveals the rapid rate at which our ore situation is becoming dangerously acute. Up until now we could have met all requirements of the steel industry from domestic reserves. The table shows that by 1960 less than three-fourths of our requirements can be met by our normal sources of supply while in 1970 less than one-half of our ore requirements can be obtained from these sources. The only way in which the 37 million tons of ore required in 1960 from new sources and the 78 million tons required in 1970 can be provided is to both hasten the development of taconite production and facilitate the inward movement of foreign ore.

fall of the St. Lawrence in the 46-mile International Rapids section, where the river runs downhill with great velocity, with an annual average discharge in the range of 240,000 cubic feet per second. It was here that the spectacular Long Sault Rapids formerly terrorized mariners. An occasional venturesome Indian might run these rapids in a canoe and survive, but for conventional navigation only locks and canals would suffice.

The terror of the mariner was the dream of the hydroelectric engineer, and New York and Ontario have long aspired to harness the river at this point, capturing the largest undeveloped source of water power in North America. In July, 1958, the great dam was dedicated, and in September, 1958, the great turbines began to spin. This year the 32 enormous turbines, sixteen on each side of the international boundary, will be in full operation, harnessing 1,200,000 horsepower of energy and producing upward of thirteen billion kilowatt hours of energy each year.

The military and industrial significance of this great new power resource is obvious. Power from this great dam will flow as much as 300 miles from the dam site, sparking new industrial developments in Ontario and eastern Quebec and aiding in developing the great mineral resources of Ontario.

On the American side, spectacular new industrial developments have been simulated by the new power source. These include a new aluminum plant being built at $100 million cost near Massena, New York, by Reynolds Aluminum Company. This tremendous plant will utilize both the navigation and the power of the St. Lawrence. Ocean ships will carry bauxite ore from distant lands to the plant, and the large concentration of power available at the site will permit the development of the first fully integrated aluminum plant in America, with raw alumina entering the plant on the river side and the finished product emerging from the far end. Significantly also, General Motors Corporation is building at Massena the largest aluminum foundry in the General Motors empire.

These are merely illustrative of the industrial developments confidently anticipated in the St. Lawrence River valley in upper New York state, in parts of New England, and in Ontario and Quebec, powered by the great energy of one of the world's mightiest rivers. The industrial capacity and the military potential of Canada and the United States are being significantly enhanced.

It is worth noting that the waters of the Great Lakes, as they fall toward the sea, not only will provide a unique combination of inland and ocean navigation, but will be one of the hardest working water supplies in the world from the power standpoint. Power is generated at Sault Saint Marie, at the downfall of Lake Superior toward Lake Huron. It is, of course, generated on an astronomical scale at Niagara Falls. The same water, moving east, will now be harnessed on an astronomical scale at the International Rapids section. Canadian power plants at several points between Massena and Montreal again send this water through their turbines on a significant scale.

Surely these must be considered among the hardest working waters of the world, with the rain droplets which fall into Lake Michigan or Lake Superior finding themselves called upon to serve the industrial and human needs of a great region; to serve the

quarter billion tons of navigation annually moving on the Great Lakes; to be harnessed for power five or six times between Lake Superior and Montreal; and finally to serve the unique combination of fresh water and salt water navigation now to be realized with the opening of the Seaway, the deepest extension of ocean navigation into a continental land mass to be found anywhere in the world.

THE SEAWAY AND SHIPBUILDING

One of the more interesting arguments for the Seaway was that it would open up vast new shipbuilding resources, both in terms of merchant marine and naval shipping. Seaway advocates argued, quite logically, that the Great Lakes Basin was the American center of steel production; that the machine shops of America lined their shores; that the country's principal reservoir of skilled manpower was to be found in the North Central region. A considerable number of shipyards are in the area, but usually working on a "feast or famine" basis with tremendous peaks of demand in wartime, and with the production curve dragging between wars. The fresh waters of the Great Lakes are conducive to long life for ships. Many of the bulk freighter fleet on the Great Lakes even now are over forty years old. The absence of barnacles and marine growths assures long life to ships in fresh water. The long life of ships on the Great Lakes is of dismay to shipyards, but of great benefit to ship operators.

In this connection, the durability of iron ships in fresh water is strongly exemplified by the fact that the USS *Wolverine*, the first iron ship ever built on the Great Lakes, launched in 1844, is still afloat as a museum piece at Erie, Pennsylvania.

During World War II more than 1,100 ships were built on the Great Lakes, a superficially impressive figure. Included in the lake buildings were fleet-type submarines, destroyer escorts, frigates, landing craft, and a host of small auxiliary naval types and small merchantmen. However, few of these ships could get to sea via the St. Lawrence, because of lock size and depth restrictions in the antiquated 14-foot waterway. Most of them reached tidewater via the Illinois Waterway and the Mississippi River, at staggering cost. Fully built and tested on the Great Lakes, they would then have superstructures cut off, and would be variously ballasted down or pontooned up to get under bridges or through shallow reaches of the inland waterway system. Reaching the Gulf Coast, sometimes in battered condition from a difficult voyage, they would then be rebuilt and re-outfitted at great cost in time and money before they could be sent into action.

THE NAVY AND THE GREAT LAKES

The U. S. Navy and the Great Lakes have a glorious historical association going back to the War of 1812. One of the clean-cut American victories of that war was the Battle of Lake Erie on September 10, 1813, when Oliver Hazard Perry, who had been commissioned to build, equip and man a fresh water fleet, destroyed the British fleet which had dominated the eastern Great Lakes, won control of Lake Erie for American arms, and handed down to posterity the great naval victory message, "We have met the enemy and they are ours."

Naval utilization of Great Lakes ship-building resources during World War II probably represented the maximum reasonably possible, under the limitations of the waterways which connect the Great Lakes to the high seas.

After the war, the Navy gave consideration in shipbuilding awards to many factors, including cost, the need to maintain a widely dispersed shipbuilding potential, and other national interest considerations. A Navy report in 1954 pointed out that Great Lakes and inland waterway yards had only about 8.6 per cent of the construction and conversion program then under way. This compared to 51.3 per cent East Coast, 28.9 per cent West Coast and 11.2 per cent Gulf. The Navy utilized lake shipyards for building minesweepers, destroyer escorts, and auxiliaries, not only to support Great Lakes shipbuilding as a military resource, but because in many instances lake shipyards had a high efficiency rating and were often low bidders.

GUIDED MISSILE SHIPS TAKE FORM ON THE GREAT LAKES

It is little known that the largest naval units ever built on the Great Lakes are now taking form at the Defoe Shipbuilding Company at Bay City, Michigan. Defoe had been awarded two contracts by the Navy for four guided missile destroyers at a total contract value of approximately $70 million. The keel for the first vessel, DDG-7, was laid in February, 1958. Delivery will be made at the Boston Navy Shipyard via the St. Lawrence Seaway, with the last of the four ships to be delivered in the fall of 1961. Here is full Navy recognition of the shipbuilding skill of the Great Lakes region and utilization of a new highway of transportation.

The naval fraternity will be interested in some of the characteristics of these historic ships. They will be 431.5 feet in overall length; 47-foot beam and with a 26-foot depth at the center line. They will displace 3,190 tons light; 3,370 tons standard and 4,500 tons fully loaded. Exact speed and power are classified, but they will travel in excess of 30 knots.

Armament will include one Tartar dual-launching missile system; two 5-inch gun mounts; two torpedo launchers; and the latest anti-submarine defense equipment. Complement will be 24 officers, 21 ratings and 309 crew.

Aluminum will be widely used in these ships. All superstructure above the main deck will be aluminum as well as much of the interior structure. All living spaces are air conditioned. Habitability is strongly stressed, and the latest in electronic equipment will be in the ships, although this information is classified.

The appearance of guided missile vessels and floating masses of intricate electronics on the historic waters of the Great Lakes and of the St. Lawrence will be a far cry from the tiny brigs and sloops, built by Commodore Perry of green lumber on the shores of Lake Erie 146 years ago.

The Defoe contract may well portend full-scale recognition by the Navy of the shipbuilding facilities of the Great Lakes. Any type of naval craft capable of moving through the St. Lawrence waterway is now susceptible of Great Lakes construction. The potential includes submarines, fleet-type destroyers, light and medium cruisers, missile ships, and escort carriers of World War II dimensions, if these were again employed.

The merchant marine construction potential includes of course the largest types of ships for Great Lakes service, exemplified by the new SS *Edmund Fitzgerald,* the largest ship ever built on the Great Lakes, 729 feet long, 75 feet wide and of 27,000 tons capacity. This type of bulk freighter will be prominent in the movement of iron ore westerly into the Great Lakes from the new Labrador Range and in the movement of bulk cargoes easterly from the Great Lakes to tidewater ports.

Great Lakes yards would of course have capacity to build all types of merchant shipping and naval auxiliaries, up to the physical limits of the new waterway. One of the already demonstrated national defense dividends of the building of the St. Lawrence thus is Navy utilization of lake shipbuilding for seaboard delivery via the new Seaway.

MILITARY VULNERABILITY

To rebut the national defense arguments in favor of the St. Lawrence Seaway, the project was invariably attacked by its opponents as being vulnerable from a military standpoint. It was argued that the project would involve strategic points such as major locks and dams which by bombing or sabotage could be taken out of service, and thus make the whole waterway inoperative. Proponents replied that if this line of reasoning were true, the Panama Canal, the Soo Locks, and the other great ship canals of the world should be taken out of service to remove the military threat they presented. It was said that the Port of New York might as well be abandoned because it too was militarily vulnerable. The underlying thought was of course that mankind does not deny itself the great works of peace because they may be vulnerable in time of war.

THE SEAWAY AND THE FUTURE

A convincing case can be made that World War II might actually have been shortened had the St. Lawrence Seaway been completed and ready for service before Pearl Harbor. The shipbuilding resources of the Great Lakes could have been used on a larger scale; an enormous power resource would have contributed mightily to the national power output, particularly to alumina production for aircraft; and a sheltered transportation route would have reduced the hazardous North Atlantic crossing by a thousand miles, with a possible large saving in ships, strategic cargo, and lives.

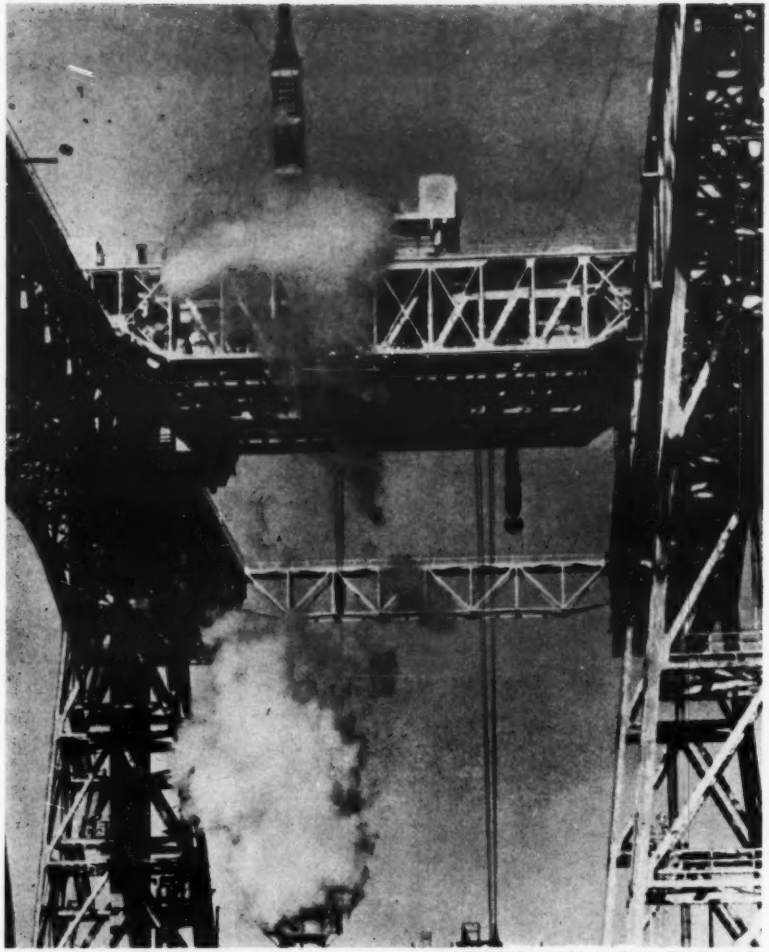
If the horror of nuclear war and of intercontinental ballistic missiles can be avoided and if future wars were to follow conventional forms, then the Seaway inescapably will be a vital factor in raw material procurement, power output, military logistics and added industrial strength. It will have a key role in continental defense considerations.

Assuming that all past patterns of military conflict are to go by the board and assuming the worst in terms of a short and deadly struggle with fantastic weapons, even then one may conclude that the St. Lawrence Project will make a contribution. Its contribution will be to help the United States and Canada build an industrial machine of such strength and magnitude that it will serve as a mighty deterrent to aggressors. The Great Lakes and the St. Lawrence, in this sense, are the arterial stream for the mighty resources of the midcontinent area, embracing steel mills, heavy industries, coal fields, petroleum, the world's richest farm lands, and great cities of skilled crafts. These are military resources of the first magnitude. These build the total complex of industrial and economic might which towers behind armies and ships.

Finally, modern diplomacy and defense are not limited to fire power. Secretary of Defense McElroy has emphasized that international trade is just as important as military agreements in buttressing America's allies. Secretary McElroy said that foreign trade strengthens the domestic economy and is essential to the economy of other friendly nations. "If stable, strong allies are important to us, then international trade is important to us," he stated.

The St. Lawrence is above all a great new mechanism for foreign trade. On its waters will flow vital raw materials from the Dominion of Canada and from many areas of the world to serve the mighty industrial machine of the Great Lakes region. From its ports will move foodstuffs and manufactured goods which, going to friendly nations and allies, will improve their way of life, strengthen diplomatic relationships, and exemplify a peaceful world of trade. From its shipyards will be launched mighty merchantmen and the navies of the future. The completion of this majestic engineering project exemplifies national sovereignty and national growth at its best and highest.

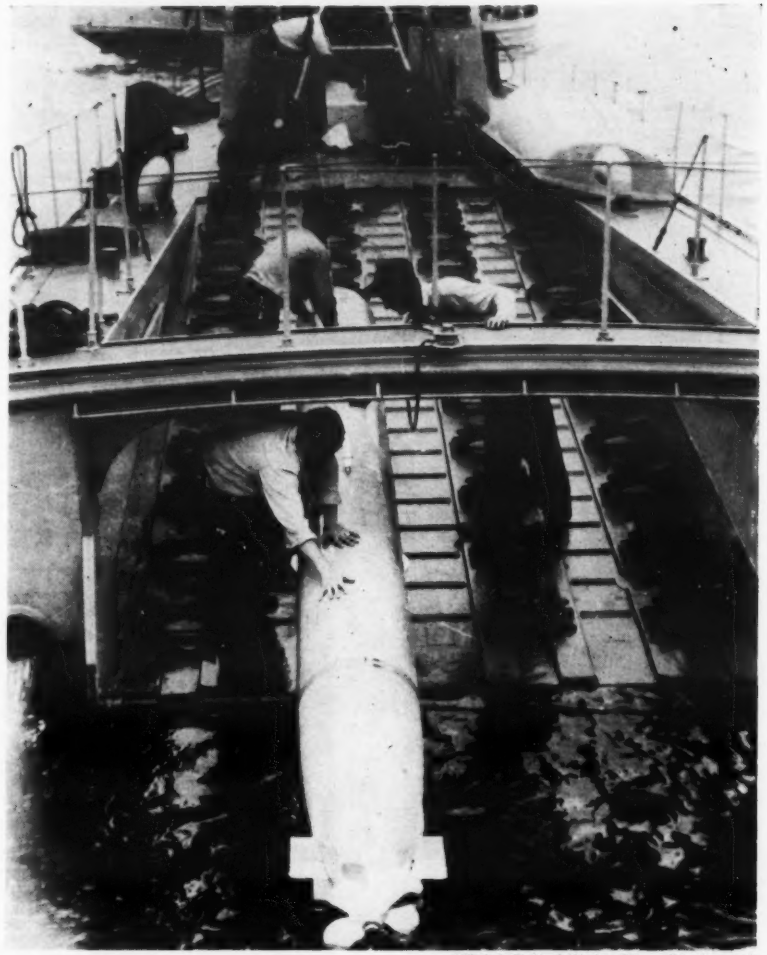
America's new fourth seacoast—the new eighth sea—the American Mediterranean—whatever we may call it, the new deep water highway to the Atlantic and the symbolic mingling of fresh and salt water in the very heart of the continent is rich with portents for a stronger and better America. It adds some powerful new muscles to national security and continental defense.



Official United States Navy Photograph

NAVY CATCHES MISSILES IN MID-AIR

Labeled "Operation Skycatch", the U. S. Navy fires and catches multi-ton dummy missiles at the San Francisco Naval Shipyard in mid-air. The newest phase of development of the launching system for the Polaris Fleet Ballistic Missile, this photograph shows a dummy missile being caught by a huge overhead assembly. This new method permits accurate study of the effects of launch stresses on the dummy missiles which are structurally identical to operational Polaris missiles.



Official United States Navy Photograph

NEW TORPEDO UNDER DEVELOPMENT BY U. S. NAVY

The U. S. Navy's New Astor Torpedo is being pulled from the water following recent test runs at the Naval Torpedo Station, Keyport, Washington. Astor is an electric high speed torpedo capable of operating at longer ranges than any presently operational underwater weapon.

JULIAN S. KOBLER

ELECTRODE WELD METAL FOR FABRICATION OF DYNAMICALLY LOADED SHIPBOARD MISSILE LAUNCHING SYSTEMS

THE AUTHOR

is a metallurgist, having attended Temple University and holding an AB degree from the University of Pennsylvania and an LLB from Rutgers University. From 1943 to 1955 he was associated with prominent welding alloy manufacturers as Research Engineer and Production Manager. Since 1956 he has been associated with the U.S. Naval Gun Factory as Supervisory Welding Engineer, Head of Fabrication Procedures Section. Mr. Kobler has been responsible for a number of major developments in electrode design and technology. He is a member of the American Welding Society, American Society for Metals, American Society of Naval Engineers and American Ordnance Association.

INTRODUCTION

The General Problem. The general concepts of weldability, though vast in scope, demand that one be apprised of theories and developments which in a practical sense may affect the fabrication and service performance of high-strength weldments. Technological obstacles heretofore encountered are rapidly disappearing. Yet today, with the advent of new materials and processes available to the industrial world, novel problems peculiar to advanced technology constantly affect those who are directly or indirectly concerned with fabrication.

Among the foremost of those facing the metallurgist and welding engineer of today is that of brittle failure. An analysis of the major factors resulting in the failure of welded structures has revealed the importance of a property of metals described as "notch sensitivity." This is defined as the relative ability or inability of a material to absorb energy and carry loads in the presence of notches and other geometries producing steep stress gradients. Unfortunately, though structures may be designed well within the yield strength of materials selected, the significance and importance of properties beyond the yield are usually only given serious consideration where high plastic ductility provides an additional safety factor. Yet it has been established that as a result of the improper selection of materials, imperfections in design or workmanship, or a combination of these factors, there are developed points of high stress concentration which may move to failure with little or no plastic deformation before full working stress can be developed in the structure as a whole. On this premise, notch sensitivity specifically with respect to the selection of materials assumes paramount importance in design particularly where contemplated service temperatures of the structure extend over a relatively wide range.

The question of the effect of temperature on the mechanical properties of steel is no longer academic but poses and continues to pose a serious practical problem in service at low and on occasion at moderate temperatures. Lowering the service temperature of steel has the same qualitative effect as increasing the rate of loading, the severity of a notch,

or the intensity of stress concentration. Long-range investigations of catastrophic failures relating to structures such as ships, bridges, pressure vessels, and others of a like nature have confirmed the fact that at low temperatures stresses only slightly above yielding may readily initiate brittle fracture at the point of origin of a sharp notch or crack below what is now termed the Nil Ductility Transition temperature of the steel. For clarity with respect to this concept as related to brittle or ductile behavior of steel, reference is made to the findings of Pellini, Puzak, and associates at the Naval Research Laboratory who have provided new and interesting theories regarding transitions.

The fundamental behavior theories expounded embrace fracture energy characteristics within three major transition zones as illustrated in Figure 1 and expressed below.

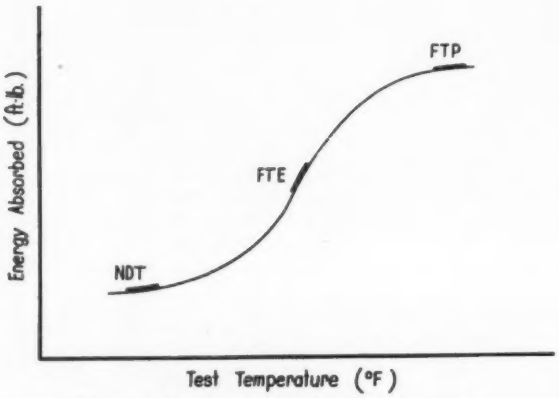


Figure 1. Fracture Transition Temperatures.

a. *The Nil Ductility Transition (NDT).* This is the temperature below which steel loses all ability to deform in the presence of a sharp notch. Fractures initiate immediately on reaching the yield point and propagate easily through the elastic loaded region.

b. *The Fracture Transition for Elastic Loading (FTE).* This is the temperature below which initiated fractures will propagate through elastically-loaded regions and above which fractures will propagate only through plastically-loaded regions. At this temperature fracture initiation must be forced. However, as the service temperature is lowered from FTE to NDT, the force necessary for fracture initiation is reduced.

c. *The Fracture Transition for Plastic Loading (FTP).* This is the temperature above which only shear tearing is possible and propagation cannot occur. Despite the severity of drastic loading, ductile failure can only occur following severe deformation. At temperatures between FTE and FTP, propagation becomes increasingly difficult.

General considerations relative to weld and base metal behavior characteristics have undergone extensive investigation over the past two decades. The introduction of low hydrogen mineral type electrodes and the advent of the shielded inert gas metal arc welding processes have provided both chemical and metallurgical control of weld deposits to a degree of equivalence experienced in orthodox steel making practice.

As a result of these concurrent developments in steels and filler metals, strength levels of fabricated weldments have increased phenomenally in recent years. Today, the tendency has been to push properties of materials to their limits. High strength-to-weight ratios have soared, and joint strengths of 300,000 psi are no longer considered out of the realm of feasibility. Coincidentally, service conditions imposed on welded structures subjected to low and high atmospheric temperatures have reached a severity encompassing low margins of safety and critical consequences of failure. Accordingly, weldability and the solutions of problems ensuing therefrom have become more complex in nature. From contemporary weldability studies there have evolved a number of basic principles for obviating brittle failure in weldments of the type under discussion. These can be classified as follows:

(1) A design which will produce a functionally-suitable structure with adequate strength under all possible service conditions, including the accident case where drastic loading occurs.

(2) Satisfactory workmanship and fabrication that will tend to carry out the intent of the design, that is, to produce welded joints of the strength intended with a minimum of notch defects.

(3) Steel plate and weld metal that possess the properties anticipated by the designer, that is, materials capable of withstanding high stresses and dynamic loading in the presence of notch defects or flaws, within a wide range of operating temperatures.

The last poses the most perplexing problem of all, for it involves the careful selection of materials that will conform to the requirements of anticipated service. It is obvious that no intricate welded structure can be realistically designed and fabricated without the existence of sharp notch defects or flaws, and thus, in the military case, materials of substantial static and dynamic properties capable of withstanding the high stresses and impacts of combat service must be considered. For this reason, selection of materials should normally be restricted to those possessing NDT and possibly FTE transitions below the minimum operating temperature of structures.

DISCUSSION

The Specific Problem. The prime problem posed in planning for the manufacture of a shipboard missible launching system designed and developed by the United States Naval Gun Factory was essentially one involving metallurgical and weldability characteristics of materials for fabrication. It was contem-

plated that this complex structure would be subject to exceedingly-high stresses and impact at service temperatures as low as 10° F. Design was further limited to rigid maximum weight requirements, and therefore, it was essential that materials for fabrication possess properties combining high yield strength and sufficient notch toughness under all service conditions, including those where dynamic loading could conceivably produce stresses beyond the yield.

As a result, selection of material was necessarily restricted to the utilization of a light gauge, high yield strength, quenched and tempered alloy structural steel. The steel designated was the recently-developed T-1 alloy, possessing a low-carbon tempered martensitic microstructure with characteristics of high strength and adequate notch ductility as indicated in Table I. These preliminaries, however, led to the specific problem of ultimate fabrication. It is well to consider at this point that the development of T-1 or any other complex alloy steel may create certain unforeseen and objectionable characteristics that must be eliminated before utilization of the material is possible. This was particularly the case in the development of procedures for the welding of subject missile launching system. An added complication was the prohibition of preheat on light gauge T-1 steel prior to welding in order to prevent possible microstructural transformation from a notch tough low-carbon martensite to a notch sensitive upper bainite. Such transformation could be anticipated as a result of retardation of the weld cooling rate.

TABLE I.
Approximate Mechanical Properties of T-1 Steel

Yield strength—0.1 offset	90,000 psi
Tensile strength	105,000 psi
Elongation in 2"	18
Reduction in Area	55
Charpy V Impact	—90°F/20 Ft. lbs.
	—45°F/25 Ft. lbs.
	0°F/30 Ft. lbs.

For purposes of adequate fabrication, where dimensional stability was of major importance, it was essential to provide for stress relief annealing during assembly. Though the steel itself, according to the manufacturer, neither decreased in strength nor notch toughness as a consequence of such stress relief, little was known concerning the reaction of weld metal subjected to such a heating cycle. The only data available at the time from either the manufacturers of the steel or the manufacturers of arc welding electrodes could be summed up as follows:

a. Up to 1956, 100 percent weld-joint efficiency could not be obtained by any weld metal deposited by a commercially-available electrode under conditions specifying stress-relief annealing.

b. In 1956, development of electrodes progressed to a level whereby stress-relieved weld metal approached the mechanical properties desired. Unfortunately, additional weldability complications were evident, and it became apparent that an electrode must be designed to meet the requisites of the missile system application.

As previously indicated, at the inception of the investigation, concern existed with respect to the possible detrimental effects of stress relieving on nondilution weld metal. Furthermore, it was conjectured that the thermal effect of welding on the metallurgical characteristics of the T-1 alloy might conceivably create a weakened area within the heat-affected zone. As a result, it was anticipated that notch sensitivity would materially increase in this zone to the extent that minimum notch ductility and resultant low-impact values would be exhibited at contemplated service temperatures. However, following a review of the test data obtained, it was evident that the major problem relating to weldability did not reflect such a condition.

Discussion of Test Procedures and Results. In cooperation with electrode manufacturers, experimental electrodes of the 110-15, 16 classification were submitted for evaluation. These will be referred to hereafter as Electrodes, A, B, C, D, and E in order of submission. The last electrode, namely electrode E, was submitted in accordance with Naval Gun Factory recommendations relative to weld metal chemistry. Table II shows a tabulation of nondilution weld metal chemistry for the entire series of electrodes. Composition of the T-1 alloy is also indicated.

TABLE II.
Tabulation of Weld Metal Chemistry

COMPOSITION OF NONDILUTION WELD METAL

Electrode No.	Percent of Element											Percent H_2O in Covering
	C	Mn	Si	S	P	Ni	Cr	Cu	Mo	V	:	
A	.07	1.40	.52	.014	.019	1.84	.66	.08	.21	—	:	.26
B	.08	1.27	.48	.022	.017	1.17	.69	.09	.41	—	:	.21
C	.07	1.54	.52	.017	.022	2.78	.06	.03	.47	.02	:	.30
D	.06	1.34	.39	.019	.015	1.69	.70	.05	.23	<.03	:	.26
E	.12	1.57	.52	.018	.015	1.03	—	—	.15	—	:	.21

COMPOSITION OF BASE METAL

Percent of Element										
C	Mn	Si	S	P	Ni	Cr	Cu	Mo	V	B
.13	.69	.14	.04	.017	.87	.50	—	.48	.06	.0046

Test procedures included the following as illustrated in Figures 2, 3, 4, 5 and 6.

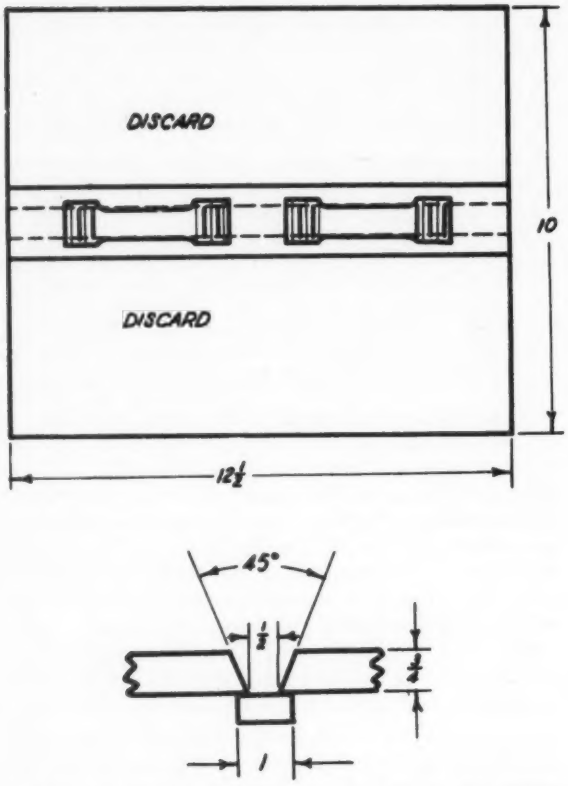


Figure 2. Unrestrained Groove Test Plate for Tensile Specimens.

All test plates were welded with identical joint welding procedures and were permitted to cool to room temperature after completion of welding. Approximately 24 hours after welding, the plates were radiographed and then subjected to an 1100°F stress relief for two hours followed by a furnace cool.

Figure 7 shows a typical radiograph of a weld made with a T-1 electrode. None of the welds examined revealed porosity, cracks or other weld metal defects.

Table III provides a tabulation of stress-relieved nondilution tensile properties. It should be noted that electrode C was excessively high in strength and failed to meet the specified ductility requirements. The remaining electrodes either approached or conformed to the required values which, incidently, reflect the properties of the T-1 alloy.

Figure 8 indicates that Charpy V transition curves for electrodes A, B, D, and E exhibited stress-relieved weld metal energy absorption levels at the predetermined critical testing temperature of 0°F, equivalent to or greater than T-1 steel. Both the NDT and FTE transitions were below expected operating temperatures for the missile system. As might be expected, electrode C exhibited notch sensitive weld metal

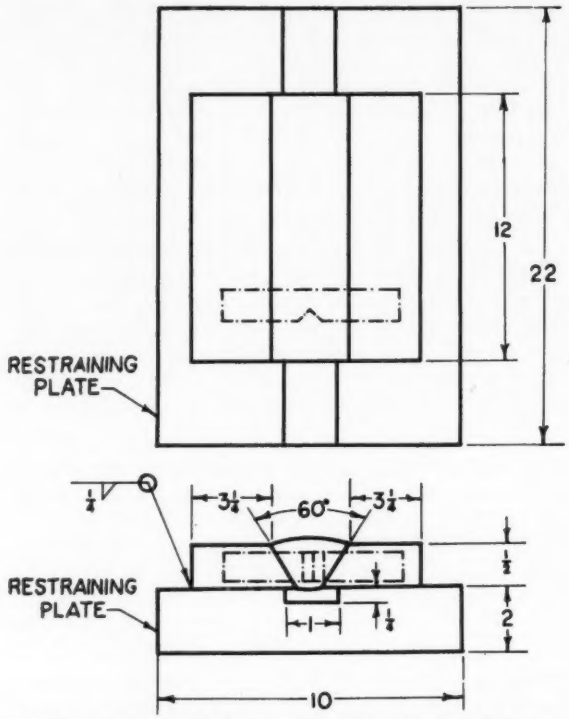


Figure 3. Restrained Groove Test Plate for Non-Dilution Weld Metal Charpy V Specimens.

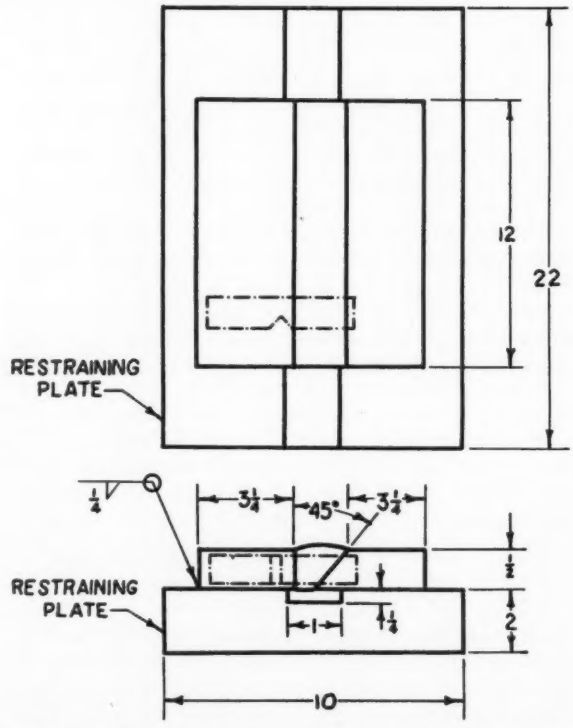


Figure 4. Restrained Groove Test Plate for Heat Affected Zone Charpy V Specimens.

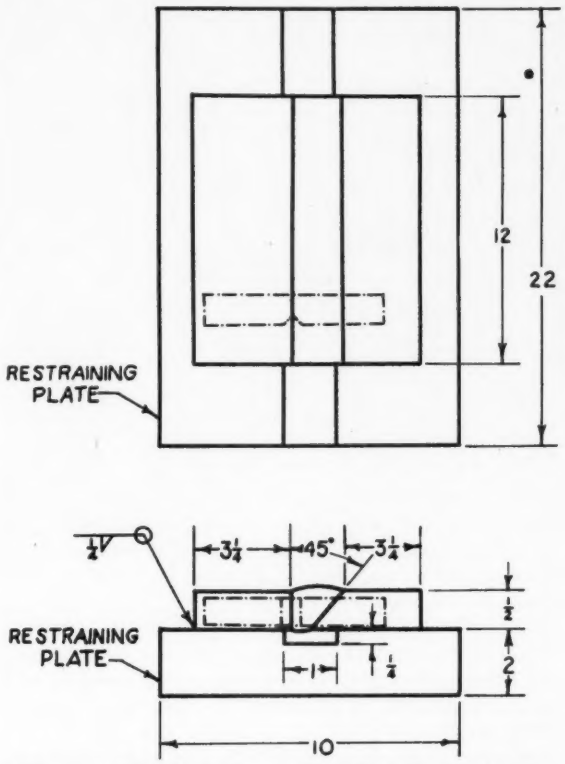


Figure 5. Restrained Groove Test Plate for Fusion Zone Charpy V Specimens.

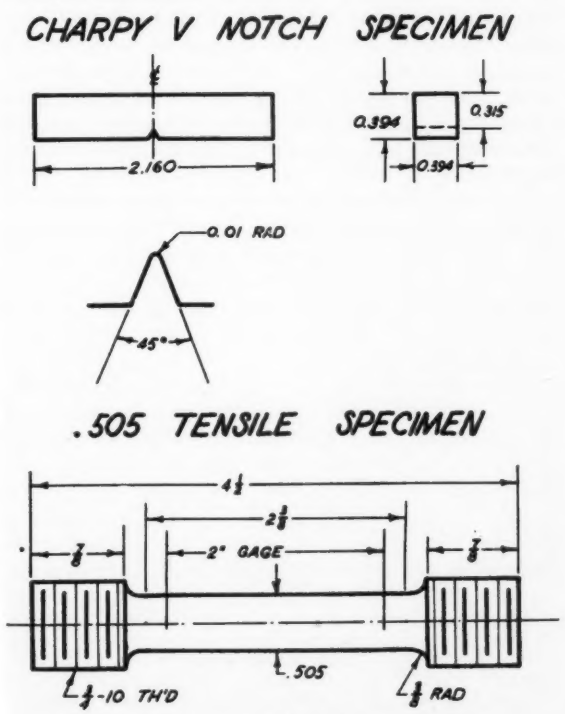


Figure 6. Impact and Tensile Specimen Details.

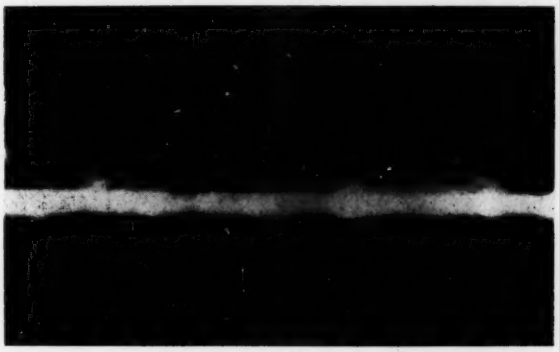


Figure 7. Typical Radiography of T-1-Electrode Weld Metal.

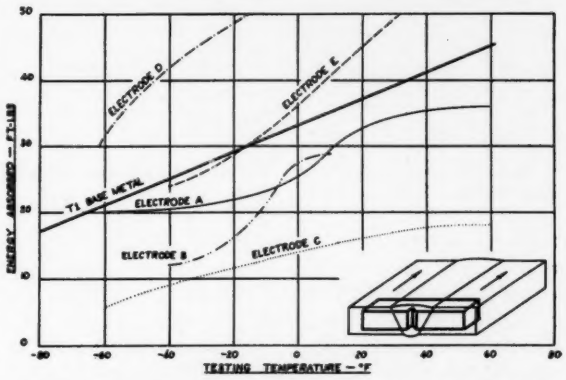


Figure 8. Charpy V Transition Curves for Non-Dilution Weld Metal Stress-Relieved 1100° F-2 Hours.

TABLE III.
Tabulation of Weld Metal Tensile Properties

MECHANICAL PROPERTIES OF NON-DILUTION WELD METAL*
Stress Relieved at 1100°F. for 2 Hours
Standard .505 Tensile Specimens

Electrode No.	Yield Strength .2% Offset	Tensile Strength	% Elongation in 2"	% Reduction in Area
A	100,500	108,500	24	66
B	108,000	126,000	23.5	59
C	124,000	133,000	13	—
D	102,500	108,000	21	63.5
E	104,500	116,000	23	61

WELD METAL REQUIREMENTS FOR 100% JOINT EFFICIENCY*

Yield Strength .2% Offset	Tensile Strength	% Elongation in 2"
100,000	110,000	18

*As welded mechanical properties are greater in strength; comparable in tensile ductility.

with energy absorption values as low as 10 ft lb at 0°F. This immediately excluded electrode C as a potentially-suitable filler metal.

Having determined that at least two electrodes were capable of producing welds of adequate strength, efforts were directed toward examining the properties of the heat affected zone. Under similar conditions of restraint, welds were deposited with electrodes A and C, the former representing weld

metal of satisfactory notch ductility, and the latter, notch sensitive weld metal.

In Figure 9, Charpy V transition curves for Heat Affected Zone indicate a significant increase in the notch ductility of the heat-affected base material welded with electrode C as opposed to the charac-

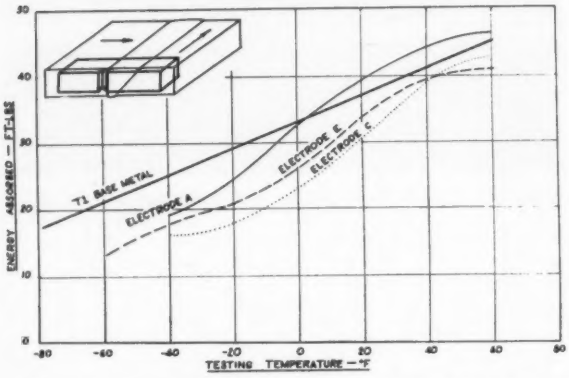


Figure 9. Charpy V Transition Curves for Weld Heat Affected Zone Stress Relieved 1100°F-2 Hours.

teristics of the filler metal itself. Observed values approached those for the affected plate joined with electrode A. In both cases, the estimated NDT and FTE transitions were below projected service temperatures of the missile-system structure. These findings discounted the existence of a significantly-weakened heat-affected zone, and thus it was apparent, particularly in view of the data obtained on plates welded with electrode E, that the thermal effect of welding on the weld adjacent areas of the T-1 alloy was negligible.

Deductively, there remained only one other weld region capable of displaying excessive notch sensitivity. This was the fusion zone. Experience has revealed that paths of failure in a weldment can move through base metal, weld metal, heat affected zone, or fusion zone. The latter cannot be described as either weld metal or heat-affected base metal but is best defined as an extremely-narrow discontinuous interface approaching microscopic dimensions. It is located at the point of juncture between the diluted area of weld metal (an homogeneous compound of weld and base metal with its own distinct chemistry) and heat-affected base metal, so noted in Figure 10.

As a result of the liquid dilution of both molten weld and base metal in the heat of the welding arc, a discontinuous change in composition occurs across the weld bead and base metal interface. This conceivably creates an area within what is commonly termed weld metal, a dilution zone of a composition unlike the nondiluted weld metal. At high temperatures below the melting point and during the cooling phenomenon, solid state diffusion may act upon this composition and partially compensate for the initial dilution effect in the region of the interface.

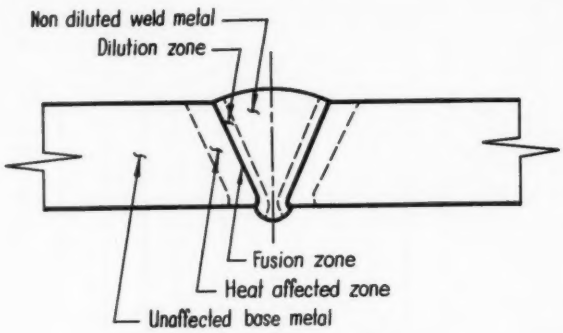


Figure 10. Weldability Zones.

However, the reaction cannot move to completion at the point of fusion because of extremely rapid cooling from the molten state. This retards the diffusion process and provides for the retention of discontinuities and single phase constituents. Where, however, solid state diffusion is capable of continuing for extended periods of time at high temperatures, these discontinuities may be eliminated, or at least minimized.

Though the chemistry of the dilution zone is capable of calculation by means of the law of mixtures, the composition of the narrow fusion zone cannot so be estimated in view of the incomplete process of diffusion.

From the metallurgical standpoint, the fusion zone tends to assume the properties of the surrounding area, and in so doing, the distinctive effect of some of the brittle phases may be somewhat relieved. This belief, however, is hypothecated on the premise that chemical incompatibility between weld and base metal is non-existent. Where such prevails, the compensating influence of diffusion on the constituents formed in the region of the interface may no longer be effective.

In view of critical service conditions anticipated for the missile launching system, it was imperative that the level of properties developed across the

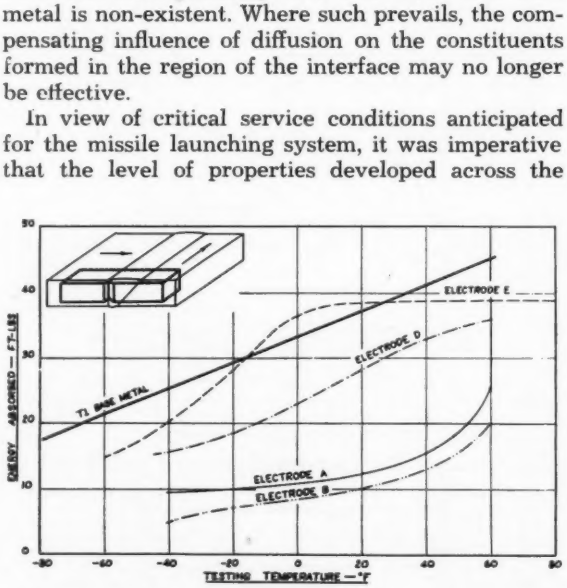


Figure 11. Charpy V Transition Curves for Fusion (Dilution) Zone Stress Relieved 1100°F-2 Hours.

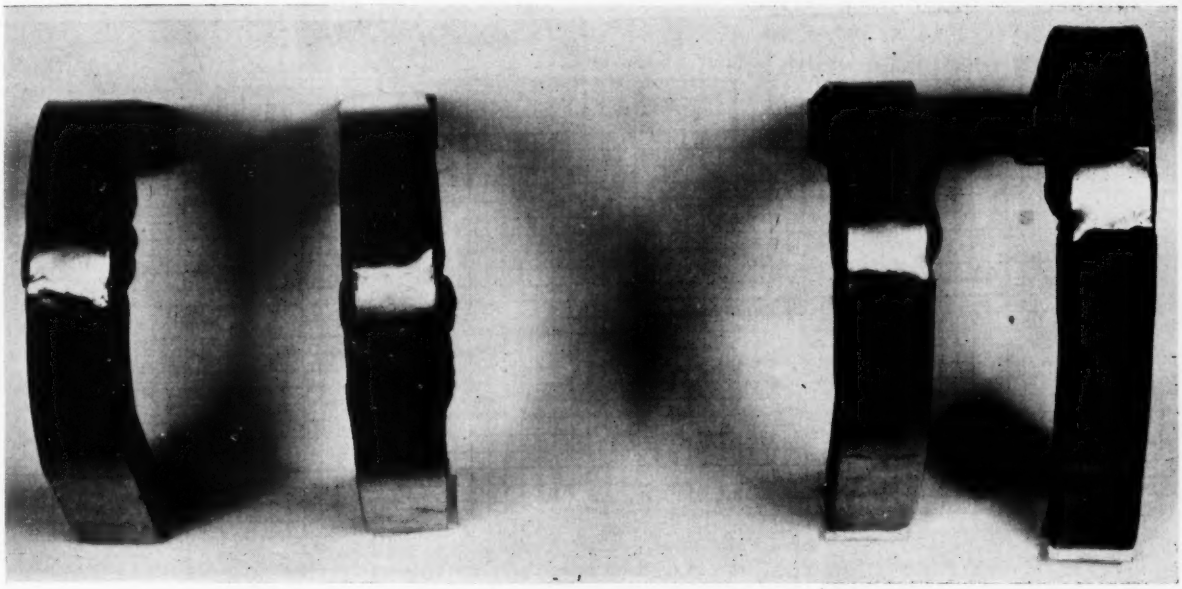


Figure 12. Photograph of Sub-Size Guided Side Bend Specimens After Test.

stress-relieved joint be commensurate with that of the T-1 alloy. If, as expected, the structure might be required to withstand stresses to the limit of its yield, it was essential that no weakened zone exist through which a crack or flaw could move to sudden and catastrophic failure.

As illustrated in Figure 11, Charpy V transition curves for fusion zone substantiated the possibilities of a notch-sensitive zone at the region of the stress-relieved weld-base metal interface for electrodes A and B. The levels of energy absorption were considerably below the unaffected base metal, comparable electrode weld metal, or heat-affected-zone values. Estimated NDT values were above contemplated service temperatures of the structure.

An analysis of the A and B electrodes resulted in a theory relating to modification in electrode design that might obviate the detrimental dilution-diffusion effect on stress-relieved fusion-zone properties, for it was obvious that if electrodes A or B were utilized for fabrication of the structure, an increasing risk of brittle failure in the notch-sensitive fusion zone would be encountered under adverse service conditions. This concept was based on alloy incompatibility existing between the weld deposit and base metal. After theoretically computing the composition of dilution zones, modifications in electrode design relating to adjustments in C, Mn, Cr, Ni and Mo were recommended as a possible solution. The suggested nominal composition initially recommended was as shown in Table IV.

No major changes were observed in electrode D other than those that probably occurred in coating ingredients and electrode processing, which facilitated a general rise in level of energy absorption for

TABLE IV.

Recommended Weld Metal Chemistry of T-1 Electrode.

C	Mn	Si	Ni	Cr	Mo
.10	1.50	.50	1.10	—	.20

weld metal and fusion zone. However, the properties of the latter were substantially below that of the T-1 alloy so that fusion zone efficiency approximated only 76 percent.

Modifications in electrode E, on the other hand, were substantial in nature and conformed to Naval Gun Factory recommendations. As previously stated, weld metal was satisfactory and fusion zone impact values, as shown in Figure 11, insured a joint efficiency of 100 percent. The NDT and FTE temperatures were both significantly below anticipated operating temperatures.

The latter data appeared to reinforce the theory of incompatability, its effect on notch sensitivity of

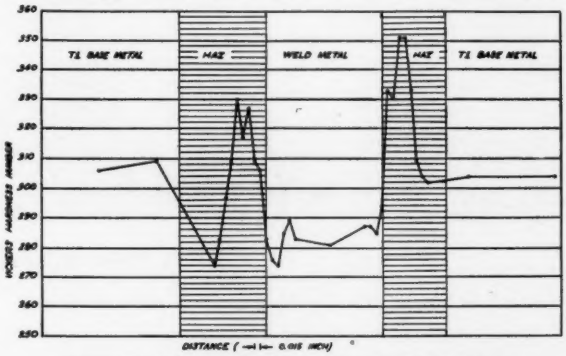


Figure 13. Vickers Hardness Survey—Electrode B.

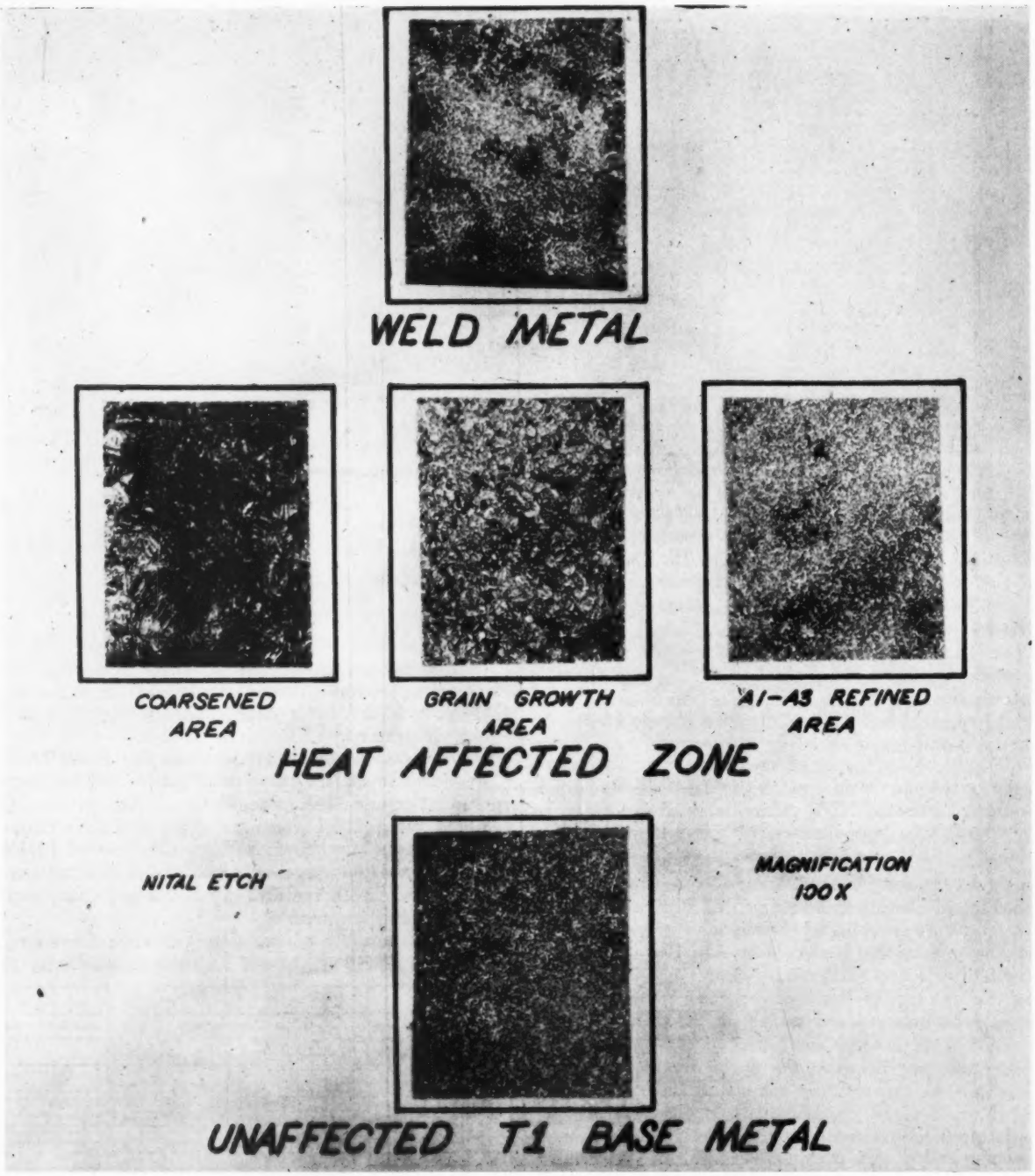


Figure 14. Typical Metallographic Survey of T-1 Weldments.

the fusion zone, and a possible means of obviating or minimizing its existence in stress relieved weldments of high-strength structural steels.

Subsequent guided side bend tests, as indicated in Figure 12, sectioned from horizontal restrained groove welds substantiated the predicted soundness of the T-1 weld joint. A hardness survey across the weld joint, as shown in Figure 13, was typical of all electrodes tested with little variation observed.

Figure 14 illustrates a metallographic survey of a typical multiple pass T-1 weld showing the inherent tempered martensite micro structures and the changes occurring from weld metal to unaffected base metal.

CONCLUSION

Weldability investigations in recent years have continued to emphasize the weld/base metal complex. In particular, the thermal effect of welding on properties of weld-adjacent zones has been over-exploited to the extent that an unfortunate void has developed in the concept of weldability.

Introduction of multiple-alloy high-strength steels has created a necessity for expansion of the weldability theory. It is concluded from evidence contained herein that a basis for continued research in the phenomenon of the fusion zone is justified. The basis premises can be stated as follows:

a. Fusion zone properties in high-strength steel weld joints are inherently brittle and retain this detrimental characteristic in the presence of dilution incompatability.

b. Fusion zone properties assume characteristics of the surrounding metal (weld and base metal) in the presence of dilution compatibility.

From the standpoint of chemico-metallurgical theory and welding engineering principles as indicated in subject shipboard-missile-launching system or extensive weldments of similar complexity, the consequences of dilution effect and the attending probability of incompatibility must be seriously considered as part of any weldability evaluation program if catastrophic failures are to be avoided. Though implied responsibilities are necessarily borne by the manufacturers of steel and filler metals, the primary responsibility rests with the metallurgist or welding engineer who has cognizance over the research, development, or fabrication of any major weldment.

Four nuclear-powered submarine construction contracts have been awarded for ships of the THRESHER class to New York Shipbuilding Corporation and Ingalls Shipbuilding Corporation. The construction of two more of this class has been assigned to the Mare Island and Portsmouth Naval Shipyards. These awards and assignments bring to 30 the total number of nuclear powered submarines now under construction or operation by the Navy.

—from BUREAU OF SHIPS JOURNAL, June, 1959

U.S.S. SKIPJACK, SS(N)-585, has completed her builders trials, testing two major submarine developments in a single hull for the first time. The endurance inherited from the propulsion plant of NAUTILUS and speed and maneuverability from the hull of ALBACORE are joined in SKIPJACK. The hydrodynamic characteristics resulted from extensive studies and tests of underwater forms, of twin and single screw arrangements, and of control surface design and arrangement. The nuclear propulsion plant represents a design advance over that of NAUTILUS, incorporating higher power and a longer life. These features, coupled with modern armament, provide a powerful addition to the Navy's submarine force.

—from BUREAU OF SHIPS JOURNAL, June, 1959

Alexander Stephen and Sons, Ltd., a British firm, has completed shop trials of one of the most powerful diesel engines in the world. The engine a twelve-cylinder, 760 mm. bore, two-stroke type, was designed for a service output of 14,000 bhp. Shop tests, however, showed its ability to produce 18,000 bhp. The engine will be used to power the CITY OF MELBOURNE, a cargo-passenger ship now under construction. Test power was developed at 126 rpm, and maintained for a twenty minute run. At the same time, the firm of Burmeister and Wain has been conducting trials on a six-cylinder engine with a bore of 840 mm. At 110 rpm this engine produced 12,500 bhp. A twelve cylinder version can produce 25,000 bhp. In the six-cylinder design, a fuel rate at 60% power of 0.33 lb per bhp-hr was reported. The engine will power an 18,500 DWT tanker for the East Asiatic Co.

—from MARINE ENGINEER AND NAVAL ARCHITECT
June, 1959

The PT-812 has recently completed conversion from a Packard gasoline engine drive to a combination gas turbine and diesel drive at the Philadelphia Naval Shipyard. The craft maneuvers and cruises by means of two 600 hp supercharged, light weight Packard diesel engines, driving two inboard shafts. Each of these shafts carries a 38 inch controllable pitch propeller, with a mechanical pitch-changing mechanism. Two gas turbines are used for higher power operations. They are 4000 shp Metropolitan Vickers G11 units, driving the two outboard shafts, each of which mounts a 52-inch propeller. The gas turbines use diesel fuel, and can be completely controlled from either engine room or bridge. They are designed for 1000 hours major overhaul interval, of which 300 may be at full rated power. The vessel has completed trials and is now in service.

—from BUREAU OF SHIPS JOURNAL
July, 1959

The Bureau of Ships has contracted with the Carrier Corporation to build a 5000 watt thermo-electric generator. A similar contract has been placed with the Westinghouse Electric Corporation. Designed as necessary developmental steps in an aim for higher power units, these generators will probably receive heat from combustion of diesel oil or other fuels readily available. The temperature difference necessary for electric power generation will be obtained by use of cooling sea water, either directly or through a heat exchanger. The electrical power output will be compatible with existing Navy electrical equipment. The generator will be designed for resistance to shock and vibration.

—from MECHANICAL ENGINEERING
July, 1959

Tewlve European nations have concluded an agreement for joint construction, in Britain, of a high powered nuclear reactor which may be a potential marine propulsion unit. The reactor is to be a high-temperature, gas cooled type. Construction is scheduled to commence early in 1960 for completion in 1962. Participating nations include England, Belgium, France, Germany, Italy, Luxembourg, Netherlands, Austria, Denmark, Norway, Sweden and Switzerland.

—from MARINE ENGINEER AND NAVAL ARCHITECT
May, 1959

ULTRASONIC ENERGY

ACKNOWLEDGEMENT

E. B. Wright, of the New Products Department, Westinghouse Electric Corporation, and R. C. Cheek, Manager of the Industrial Electronics Department, Westinghouse Electric Corporation, are the authors of this article, which appeared in the May 1959 edition of "Westinghouse Engineer."

High-frequency sound is now being developed into a useful and versatile tool for industry. The first important practical application of ultrasonics was in sonar systems, which were perfected just before World War II. Shortly thereafter, systems were developed for detecting flaws in castings, forgings, and other products. These are perhaps the most obvious applications of ultrasonic energy, because both underwater bodies and internal flaws are located by measuring the elapsed time between an initial pulse and its reflection.

When the sound intensity is increased well above that needed for detection systems, a whole new area of applications arises. For instance, ultrasonic energy can be used to tin without flux, weld, drill, clean, speed up chemical reactions, and perform a host of other jobs. While these potential applications have been discovered since World War II, equipment to do these jobs is in various stages of development. For instance, at Westinghouse, ultrasonic cleaning tanks have moved from the laboratory to the production line; other areas of application are in the advanced development stage.

THEORY

The dividing line between sonic and ultrasonic vibrations, which occurs at about 17,000 cycles per second, is based on the upper limit of the frequency response of the human ear, not on basic changes of the wave.

Fundamentally, a sonic or ultrasonic wave is a deformation of a physical medium, consisting of alternate compressions and rarefactions that travel through the medium. The velocity of the wave depends largely on the physical properties of the material. For instance, in a thin solid rod, the velocity of a longitudinal wave is given by the relationship,

$$c = \sqrt{\frac{E}{\rho}}$$

where E is the modulus of elasticity of the material, and ρ is density of the material.

Similarly, in a liquid or gas the velocity is given by the relationship,

$$c = \sqrt{\frac{G}{\rho}}$$

where G is the adiabatic compression factor, and ρ is the density.

The velocity of propagation in most solids ranges from 7000 to 20,000 feet per second. The velocity changes to some extent with temperature, pressure, and with sound intensity. The effects of temperature and pressure are most pronounced in the case of a gas.

As in most wave phenomena, the wavelength corresponding to a given frequency can be determined directly from the following equation,

$$\lambda = \frac{c}{f}$$

where c is the velocity of sound, and f is frequency. At a frequency of 20 kilocycles per second, one wave length is equal to 2.8 inches in water and 11 inches in steel.

The intensity of a plane longitudinal sound wave in any medium is given by the relationship,

$$I = k\ A^2 f^2 \rho c$$

where A is the amplitude of vibration, f is frequency, ρ is density, k is the constant of proportionality, and c is the velocity of sound in the medium.

To obtain an acoustic intensity of 100 watts per square inch in water at a frequency of 20 kilocycles per second, a displacement of 2.6×10^{-5} inch is required. However, to produce an equivalent intensity in air under standard conditions, the displacement must be increased to 1.47×10^{-8} inch because the specific acoustic impedance of air is only 1/3000 that of water. The *specific acoustic impedance* is defined by the relationship,

$$Z = \rho c$$

where ρ is density of the medium, and c is the velocity of sound in the medium.

Sound waves cannot be propagated through a vacuum as can electromagnetic waves. However, they can be attenuated, refracted, reflected, or diffracted in much the same way as light waves. The amount of sonic or ultrasonic energy that can be transmitted through a medium depends largely on the physical characteristics of the medium. For instance, a solid material will fracture if the repeated stresses set up by the zones of compression and rarefaction exceed the endurance limit of the material. In a liquid, a phenomenon known as cavitation occurs when the sound intensity exceeds a certain threshold value.

Cavitation can be described as the formation and subsequent collapse of minute vapor pockets caused by vibrational stresses in the liquid. The collapse of these cavitation bubbles can result in localized pressures up to 75,000 p.s.i. or higher and localized temperatures up to 20,000°F. Cavitation effects are extremely useful in a number of industrial processes.

ULTRASONIC SYSTEMS

Both sonic and ultrasonic applications can be classified into three categories: those requiring high acoustical energy but not cavitation; those requiring high acoustical energy and cavitation; and those requiring only small amounts of acoustical energy.

Systems used in applications requiring high acoustical power consist primarily of the following major components: the generator, the transducer, and the coupling device.

The *generator* converts the 60-cycle power to a high frequency or to another form that can be used to drive a transducer unit. The electronic generator is widely used for this purpose; however, the motor-generator set is now being used in high-power applications. At a power level of about 25 kw or greater, the motor-generator set has a definite cost advantage and requires less maintenance. However, the motor-generator set is limited at present to a maximum frequency of about 20,000 cycles per second; hence, for higher frequencies, the electronic generator must be used.

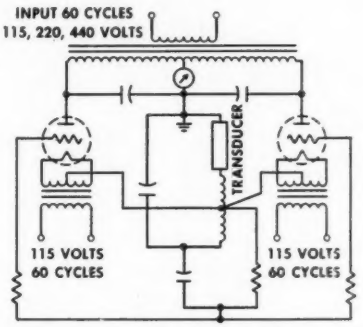


Figure 1. Components of the electronic generator are reduced by using alternating current for a plate supply; the 120-cycle envelope does not decrease the effectiveness of the magnetostrictive transducer. Standard cleaning tanks are made in 1½-gallon to 32-gallon capacities. Transducers can be fitted on larger tanks, and existing tanks can be equipped with submersible units.

The electronic generator circuit now used in Westinghouse ultrasonic equipment (Figure 1) involves a minimum number of electronic components. Since in most high-power systems, the generator represents about two-thirds of the cost of the system, generator simplicity is of paramount importance, and with fewer components, equipment reliability is improved.

The *transducer* unit converts the high-frequency electrical energy from the generator to vibrational energy. Most ultrasonic transducer units operate on either magnetostrictive or electrostrictive principles, for while a variety of transducer types can produce high-frequency vibrations, they are not used widely because of technical or commercial reasons.

The magnetostrictive transducer usually consists of a laminated stack of magnetic metal about which is placed a winding, Figure 2. When an alternating current passes through the winding, the magnetostrictive material changes its dimensions in synchronism with changes in the induced magnetic field. The resulting vibrations can then be coupled to the work piece by some suitable means.

A spaced-lamination magnetostrictive transducer has been designed especially for the irradiation of liquid baths and can be applied to operations such as cleaning, electroplating, degreasing, and pickling. The spaced-lamination construction provides an improved acoustical match between the transducer and the liquid, considerably increasing the efficiency of the magnetostrictive transducer. At the same time,

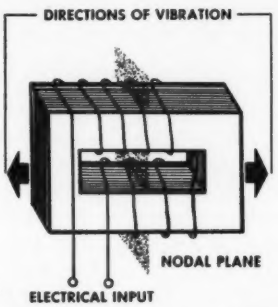


Figure 2. The magnetostrictive material vibrates in synchronism with current in the winding. The acoustic impedance of the spaced laminations closely matches that of the liquid bath.

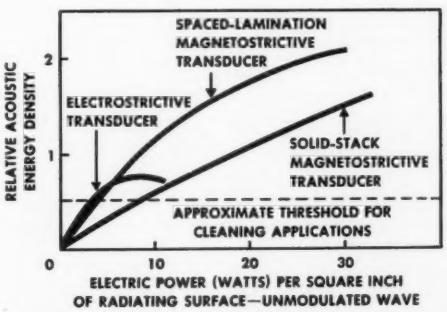


Figure 3. Comparison of typical transducers.

high intensities can be obtained. Also, the spaced-lamination unit can be constructed to irradiate liquid baths having temperatures as high as 400°F. Because of a high-temperature capability and ruggedness, the magnetostrictive transducer is suitable for high intensity, process applications, Figure 3.

The electrostrictive transducer, in its simplest form, consists of a block of material such as barium titanate or a Rochelle salt that changes its dimension with an impressed electric field. The electric field can be established between conductive coatings on opposite sides of the block.

The electrodynamic transducer is used primarily for transmitting sound energy into air or a gas with a low specific acoustic impedance; a typical example is a radio speaker. The transducer consists of a movable coil placed in a magnetic field so that an alternating current in the coil causes it to vibrate. A suitable diaphragm, attached to the coil, serves as the radiating element.

Of somewhat less importance is the electromagnetic transducer, which depends upon a magnetic attraction across an air gap. Although this type of electromechanical conversion is frequently found in relays and similar devices, it is not used extensively for the production of high-frequency vibrations. Both the electromagnetic and the electrodynamic type of transducer are more useful at sonic frequencies.

Another electromechanical transducer, sometimes used to radiate sonic energy into a gaseous medium, operates on the principle of electrostatic attraction. The electrostatic transducer consists of two parallel plates between which an alternating field is established; this creates an alternating attractive force to produce the desired vibration. Because the spacing between the plates must be quite small, the vibration amplitude is limited.

The jet, whistle, or siren is used in the chemical industry for homogenization and emulsification of liquids. For instance, dissimilar liquids can be forced through a jet in an unstable or fluctuating flow, and cavitation produced by the vibrations will homogenize the liquids. These transducers generally operate in the sonic frequency range; at higher frequencies, the efficiency is reduced.

The *coupling horn* (Figure 4) often is used in conjunction with the transducer unit in applications such as cutting, drilling, soldering, and welding, where large displacements are required to provide

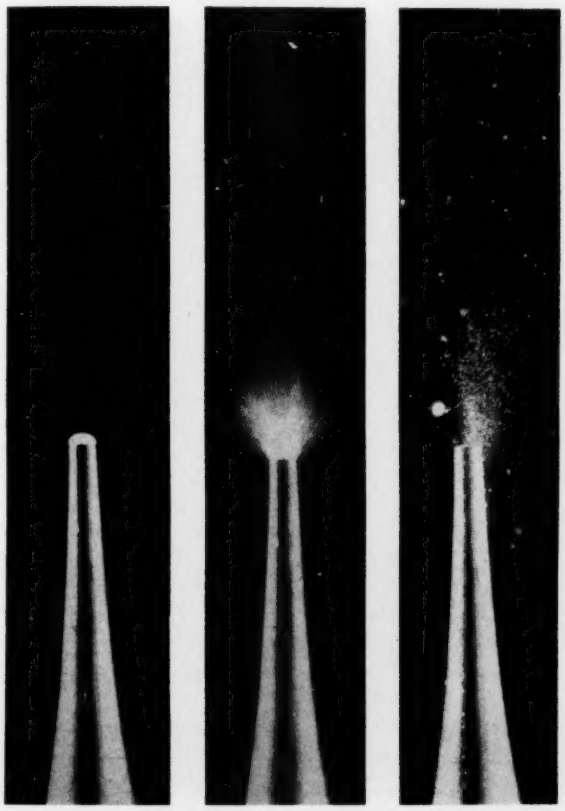


Figure 4. Though the movement of this coupling horn is imperceptible at 20,000 cycles per second, a drop of water is instantly vaporized by the vibrational energy.

a high energy level in a small area. The horn serves as a mechanical transformer that increases the vibration amplitude in proportion to the inverse ratio of the diameters of its two ends. Generally, such transformers are one-half wavelength long and are tapered to be linear, exponential, catenoidal, etc., depending on the transmission characteristics desired. If made of a suitable material, these devices are highly efficient.

APPLICATIONS

The most important high-power application of ultrasonics in industry is that of cleaning or degreasing; with ultrasonics, cleaning can be done both faster and better.

Cleaning is accomplished primarily through the effects of cavitation. The cavitation implosions occur near the surfaces to be cleaned, literally blasting the dirt loose. Because the intensity required to produce cavitation decreases rapidly with decreasing frequency, down to about 40-kc, most cleaning systems operate in the 20-kc to 40-kc range. Appreciably below 20-kc, a larger transducer is required, and the audible noise generated is undesirable.

Ultrasonic energy has been applied experimentally to electroplating processes, resulting in a decreased plating time, often with simultaneous improvement in the quality of the plate. However, despite this potential, additional techniques have to be developed before ultrasonics is applied to large-scale electroplating operations.

A number of experiments have shown that the acid removal of scale can be increased by factors of two to six or more with the use of ultrasonic energy. As more suitable equipment for high-temperature bath agitation becomes available, this technique will be used more extensively. The spaced lamination transducer is already being used for such applications.

The use of ultrasonics in decontaminating radioactive parts makes possible remote cleaning before handling by maintenance personnel, and as in the case of most ultrasonic cleaning processes, a substantial reduction in the cleaning time can be realized as well as an improvement in cleaning.

Impregnation of various electrical components can be accomplished through the use of ultrasonic energy, especially parts consisting of a laminated structure. Preliminary experiments indicate that through the use of ultrasonic energy, vacuum equipment normally used in certain impregnation processes can be eliminated.

In the chemical industry, ultrasonics can be used to emulsify immiscible liquids, homogenize liquids and solids, and hasten chemical reactions. For instance, water-mercury and water-oil emulsions can be produced. Strangely, the mercury emulsion requires no cavitation, whereas the oil emulsion does. In general, frequencies in the sonic range are more effective in these particular processes.

When a cast material is treated with ultrasonic energy during solidification, the grain structure is refined (Figure 5), eliminating planes of weakness in the casting, and making the material more susceptible to forging on other working operations. Also, the segregation of alloy constituents can be reduced, producing more uniformity in the alloy, and in some instances, the melt becomes degassed, making possible a less porous, more perfect casting. This technique may allow the production of alloys not possible with present methods.

Ultrasonics has become an important tool in cutting, grinding, milling, machining, and drilling operations. In these applications, an abrasive slurry generally is deposited between the vibrating tool and the work piece. The slurry particles, driven by the tool tip, perform the desired chipping or cutting operation. This nonrotary motion is ideal for cutting irregularly shaped holes.

Experiments show that hard materials that cannot be readily drilled by conventional means can be cut by this method. Even diamond has been removed at a practical rate using a diamond dust abrasive. Other materials that can be cut include hardened tool steel, carbide steel, ceramics, ferrites, germanium, silicon,

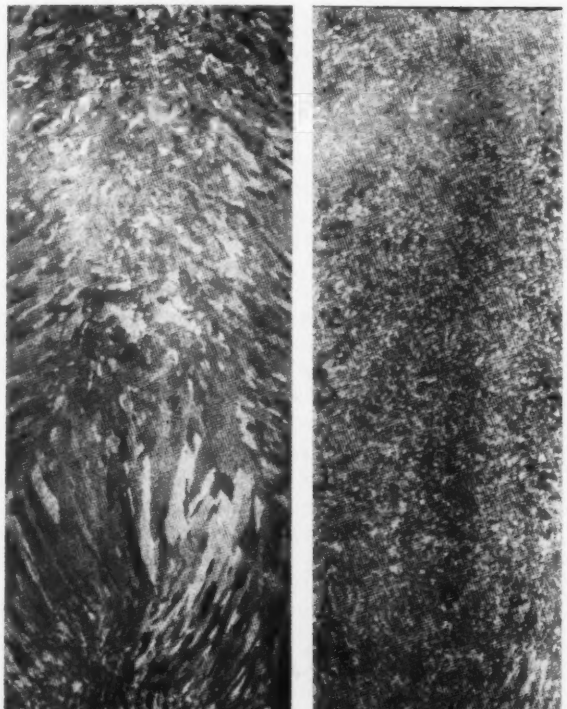


Figure 5. By subjecting a metal to ultrasonic vibrations during the casting process, the grain structure can be refined (right), resulting in an improved material.

and various jewel stones. Softer materials are not readily cut or drilled by this technique because the slurry particles indent or are embedded in the soft surfaces.

Materials such as aluminum and its alloys can easily be soldered or tinned with ultrasonics (Figure 6). Cavitation set up by the vibrational waves in

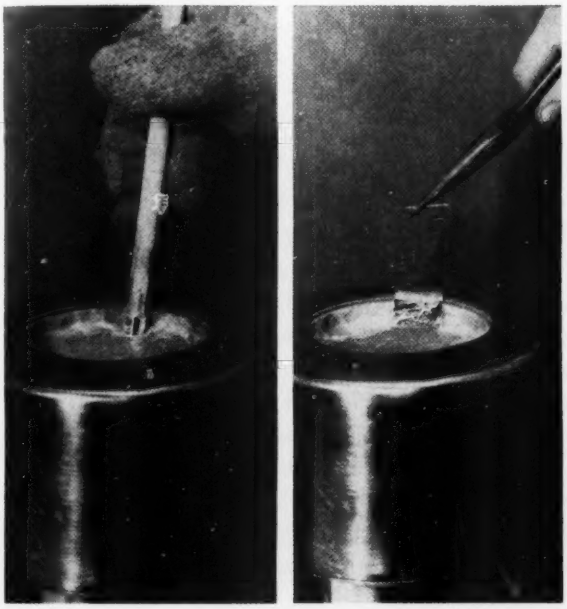


Figure 6. Ultrasonic tinning baths, now under test, can tin aluminum, ceramics, and even glass without flux or cleaning material.

the solder removes the oxide from the surfaces. Once the oxide has been rmoved, the molten solder wets the base material. Both hand gun and dip bath operations are now being used. In all cases, the vibrating tool tip must be close to the surface, since cavitation intensity cannot be maintained for more than one-eighth to one-quarter inch from the tool tip.

Materials can be welded ultrasonically without any auxiliary material. The parts to be joined are placed on an anvil; the vibrating element is lowered under pressure, and the reciprocating motion of the probe breaks off the oxide layer on the surfaces, and produces a pure cold-formed bond. An experimental seam welder operating on the same principle has also been constructed (Figure 7). Ultrasonic or sonic welding is particularly useful for joining dissimilar materials, such as copper and aluminum, that cannot be welded conveniently by other means. Also, thin foils can be joined easily. Generally, one of the materials must have a thickness of 0.100 inch or less, but the thickness of the second material or component is not critical. The soldering, tinning, and welding processes usually are accomplished in the 10- to 40-kc range.

Ultrasonics has been used extensively for flaw detection and instrumentation purposes. The ability of high-frequency waves to "see" inside large castings and other solid materials makes it extremely useful. The principle is somewhat the same as that used in radar systems. The primary difference is that sound waves are used rather than electromagnetic waves. Frequencies above 500-kc and very low power levels are most suitable for this purpose. The high frequency makes possible a smaller transducer device, and more important, provides better resolution, allowing the detection of smaller flaws. In general, as the cross-sectional dimension of the flaw decreases below about one-eighth wavelength, detection becomes difficult.

In addition, sound waves are used in a number of other instrumentation operations including depth measurements, liquid-level sensing, flow-rate measurements, viscosity measurements, grain-size measurements, and thickness measurements. Most of these operations also require the use of a high-fre-

Figure 7. Each wheel of this experimental ultrasonic seam welder vibrates in a flexural motion. The rubbing breaks off the oxide layer between the two aluminum strips and produces a clean cold-formed bond.

quency transducer operating at a very low power level. A considerable amount of electronic gear generally is required in such systems to present the information in a form that can be readily interpreted.

SUMMARY

The fascinating aspect of ultrasonic energy is that it can be applied in many different ways, with completely different results. Many new ultrasonic devices are now in the experimental stage and new applications constantly arise, which is a strong indication that ultrasonic energy will become an important and useful tool for industry.

A dual-cycle, boiling water type nuclear power plant will be built at the mouth of the Garigliano River in Italy, approximately midway between Naples and Rome. The International General Electric Company won the bid in competition with eight other firms. The plant will have a net electrical capacity of 150,000 KW and it will contribute substantially to the electric power production in central and southern Italy.

A steam-water mixture in the primary coolant loop at 990 psia will enter a steam separator from the reactor. About 1 1/2 million pounds per hour of steam, at about 99 per cent quality, will then enter the turbine throttle at a temperature of about 540°F. The primary water from the separator will then pass into a heat exchanger and produce nearly 1/2 million pounds per hour of secondary steam at 475 psia and 462°F., which will be introduced into a suitable stage in the turbine.

The fuel is to be slightly enriched uranium dioxide, compressed into cylindrical pellets which will be encased in a zircaloy tubular jacket to comprise one fuel rod section. Four such sections joined by screw connectors will make one fuel rod, nearly ten feet in length. Thirty-six rods in a 6 X 6 square form an element, of which there will be 384, containing a total of 91,000 pounds of fuel.

—from NUCLEAR ENGINEERING, May, 1959

S. F. BORG

THE MAXIMUM PRESSURES AND TOTAL FORCE ON STRAIGHT-SIDED WEDGES WITH SMALL DEADRISE

THE AUTHOR

is Professor and Head of Civil Engineering at Stevens Institute of Technology. He has a bachelor's and a master's degree in Civil Engineering and the degree Doctor of Engineering from Johns Hopkins University (Aeronautics).

He has had responsible industrial engineering design and research experience and has taught at the University of Maryland and the Naval Postgraduate School before coming to Stevens. His research in hydrodynamics, structures and other fields of applied mechanics has been published in leading scientific journals. He is author of the book "An Introduction to Matrix-Tensors Method in Theoretical and Applied Mechanics," is a member of Tau Beta Pi and Sigma Xi and a Fellow of the A.A.A.S.

SUMMARY

A new theory for solving wedge-entry problems is utilized to give an approximate solution for the pressures and forces acting on blunt (small deadrise angle) straight sided wedges. Closed form analytical expressions are given for the maximum pressures, pressure at any point and total vertical force acting on a blunt symmetrical wedge entering an infinite ocean at constant vertical velocity.

INTRODUCTION

When a blunt straight-sided symmetrical wedge enters an infinite ocean at constant velocity, there are two points of peak pressure on the wedge. This effect occurs during slamming and the determination of these pressures is a problem of fundamental interest to Naval Engineers since the local hull structural design may be governed by these pressures. Figure 1 shows a typical case and indicates that the high pressures occur at the point and also in the neighborhood of the curve of the free streamline.

In this paper, the results of a previous study[1] are given for the approximate values of the peak pressures, P_0 and P_A. Also, the total vertical force acting on the wedge face is given. It will be shown that for blunt wedges (i.e., very small values of β), to the approximation used herein, the pressures are given by,

$$\frac{P_0}{\frac{1}{2}\rho V^2} = \frac{2}{\beta} \quad \ldots\ldots(1)$$

and

$$\frac{P_A}{\frac{1}{2}\rho V^2} = \frac{2.25}{\beta^2} \quad \ldots\ldots(2)$$

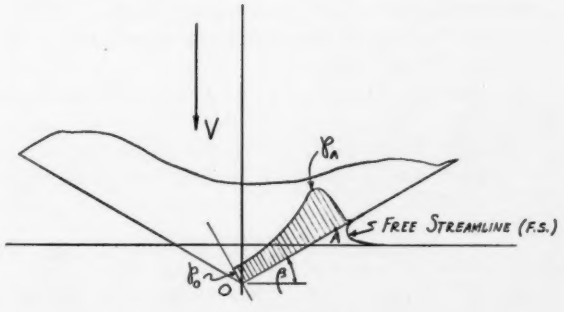
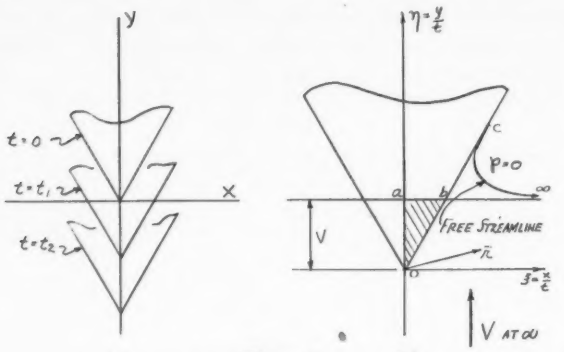


Figure 1.



(a) **Figure 2.** (b)

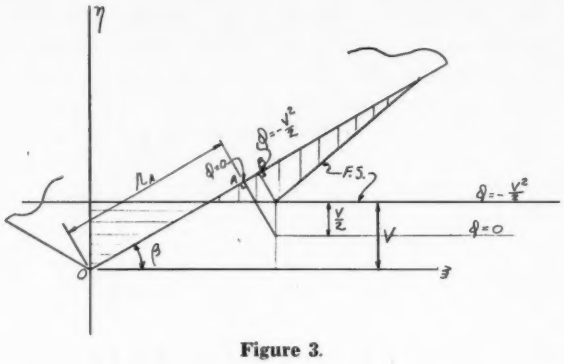


Figure 3.

The pressure at any point, ξ, on the wedge is given by (See Figure 3),

$$\frac{P_\xi}{\frac{1}{2}\rho v^2}=2\sqrt{\left(\frac{r_A}{v}\right)^2-\left(\frac{\xi}{v}\right)^2}-\frac{\xi^2}{(r_A^2-\xi^2)}+\frac{2\xi^2}{v\sqrt{r_A^2-\xi^2}}-2 \quad \ldots\ldots(3)$$

and the total vertical force on one face is given by,

$$\frac{P_v}{\frac{1}{2}\rho v^2 r_A}=\left\{\frac{1.5\pi}{\beta}-\tfrac{1}{2}\log_n\left(\frac{9}{\beta^2}\right)-1\right\}t \quad \ldots\ldots(4)$$

PROCEDURE

Consider a straight sided, infinitely long, two dimensional wedge moving at constant vertical velocity v and entering an infinite ocean. (A theory identical to that which follows holds also for three dimensional wedges.) Equivalent in every way, but more convenient for our purposes, is the case of the wedge stationary and the ocean moving vertically upward with constant velocity v, and engulfing the wedge.

In the physical x,y,t plane, this unsteady phenomenon maps as shown in Figure 2a for times $t=0$, $t=t_1$, $t=t_2$. If we introduce new coordinates, $\left|\begin{array}{l}\xi=\frac{x}{t}\\ \eta=\frac{y}{t}\end{array}\right|$ then in the (ξ, η) plane the phenomenon is shown on the single map, as in Figure 2b. From this point on all statements refer to the (ξ, η) plane, which, in analogy to a similar transformation with cone-shapes, we call the "conical" plane.

Because of continuity, the following two conditions hold,

(a) The fluid displaced by the wedge must appear above the undisturbed free streamline position, or

$$\text{Volume o a b} = \text{Volume b c } \infty \quad \ldots\ldots(5)$$

(b) The length of the free surface line remains constant with time, or

$$\text{Length a b } \infty = \text{Length c } \infty \quad \ldots\ldots(6)$$

A fundamental quantity in this formulation is the "reduced velocity, $\bar{Q}$," defined as

$$\bar{Q}=\bar{q}-\bar{r} \quad \ldots\ldots(7)$$

in which

$\bar{q}$ is the actual physical velocity at a point in the (ξ, η) plane

r is the distance, in the (ξ, η) plane, of this point from the origin.

Because the flow is irrotational, a potential function, ϕ, exists, such that

$$-\bar{q}=-(u, v)=\nabla\phi=\left(\frac{\partial}{\partial\xi}, \frac{\partial}{\partial\eta}\right)\phi \quad \ldots\ldots(8)$$

In addition, it is shown that (because of continuity)

$$\nabla^2\phi=\left(\frac{\partial^2}{\partial\xi^2}+\frac{\partial^2}{\partial\eta^2}\right)\phi=0 \quad \ldots\ldots(9)$$

everywhere on the field, and

$$\phi=\frac{Q^2}{2}+\frac{P}{\rho}-\frac{r^2}{2} \quad \ldots\ldots(10)$$

everywhere, with P and ρ the pressure and density, respectively.

It may also be proven that, along the wedge face, P will be a maximum where $Q=0$. That is

$$\frac{P_{MAX}}{\frac{1}{2}\rho v^2} \text{ occurs where } Q=0. \quad \ldots\ldots(11)$$

Finally it is shown that on the F.S., at infinity

$$\phi=-\frac{v^2}{2} \quad \ldots\ldots(10a)$$

There are many other relations and properties which hold for this formulation of the problem—see Reference 1. However, for our purposes, the above are sufficient, and we summarize them as follows: The solution for the unsteady flow problem of Figure 2b requires finding a function, $\phi\ (\xi, \eta)$, which satisfies

(a) $\nabla^2\phi=0$, everywhere in the field

(b) $\frac{\partial\phi}{\partial n}=0$, along the wedge face, where n is the direction of the normal to the wedge

(c) $\frac{\partial\phi}{\partial\eta}=-v$ at infinity

(d) $\phi=\frac{Q^2}{2}-\frac{r^2}{2}$ along the free streamline (since P=0 here). Hence

(e) $\phi=-\frac{v^2}{2}$ on the F.S. at ∞

It is possible to obtain ϕ functions which satisfy all of the above except (d) by utilizing the potential flow solutions for classical, irrotational steady state motion. These may be taken as approximate solutions to the problem.* Having ϕ, using Equations (8) and (10) we can obtain the pressure acting on the body.

In particular, the solution for the problem being considered herein may be obtained by utilizing the flat-plate potential solution.[2] The flow function, w, is given by

$$w=\phi+i\psi=-iv\sqrt{z^2-d^2} \quad \ldots\ldots(12)$$

and the application of the above relations to the stagnation point, O, gives, (neglecting a higher order term)

$$\frac{P_0}{\frac{1}{2}\rho v^2}=\frac{2}{\beta} \quad \ldots\ldots(1)$$

To find the peak pressure at A, we approximate the free streamline. To this approximation, and because $\beta\to 0$, the peak pressure will occur between A and B, since $Q=(q-r)=0$ here.†

It will be sufficiently accurate to assume $Q_A=0$. Therefore, from Equation (10),

$$\left(\frac{P}{\rho}\right)_{MAX}=\frac{P_A}{\rho}=\frac{r_A^2}{2}+\text{higher order terms} \quad \ldots\ldots(13)$$

*In essence, we have solutions which satisfy the field equations and all the boundary conditions except those along the F.S. (except at infinity). This is typical of all approximate wedge entry solutions.

†For the conditions of Figure 3.

$q_B\cong 2r_A, > r_A$

$q_A\cong\frac{v}{\beta}, < r_A$

$Q=q-r=0$ between A and B

or

$$\frac{P_A}{\frac{1}{2}\rho v^2}=\left(\frac{r_A}{v}\right)^2 \quad \ldots\ldots(14)$$

Now, utilizing the continuity requirements (5) and (6) we find for the case of Figure 3,

$$\frac{r_A}{v}=\frac{1.5}{\beta} \quad \ldots\ldots(15)$$

so that

$$\frac{P_A}{\frac{1}{2}\rho v^2}=\frac{2.25}{\beta^2} \quad \ldots\ldots(2)$$

In order to determine the total vertical force acting on the body, it will be necessary that the pressure over the entire wedge be integrated and the vertical component of the force taken. Recalling that

$$|q|=\frac{dw}{dz}=-\frac{ivz}{\sqrt{z^2-d^2}} \quad \ldots\ldots(16)$$

and using Equation (10) along the wedge face, we find that at any point ξ, the pressure is given by,

$$\frac{P_\xi}{\frac{1}{2}\rho v^2}=2\sqrt{\left(\frac{r_A}{v}\right)^2-\left(\frac{\xi}{v}\right)^2}\,\frac{\xi^2}{(r_A^2-\xi^2)}+\frac{2\xi^2}{v\sqrt{r_A^2-\xi^2}}-2 \quad \ldots\ldots(3)$$

The total vertical force is then obtained by integrating Equation (3) along the wedge face and taking the vertical component of the result. This is a straight forward integration and leads at once to the following expression for P_v, the vertical force on one face of the wedge,

$$\frac{P_v}{\frac{1}{2}\rho v^2 r_A}=\left\{\frac{1.5\pi}{\beta}-\frac{1}{2}\log_n\left(\frac{9}{\beta^2}\right)-1\right\}t \quad \ldots\ldots(4)$$

CONCLUSION

By utilizing various newly derived relations, approximate expressions were obtained for the two peak pressure points on straight-sided symmetrical wedges entering an infinite ocean at constant velocity, and also for the total vertical force on one face of this wedge.*

*The analysis presented herein neglects compressibility effects of the fluid. In general this is a reasonable assumption. However, there is a very short time period immediately following impact when compressibility effects are important. A solution for this phase of the impact phenomenon is presented in a paper by the author "Initial Wedge Impact on a Compressible Fluid." *Journal of Applied Physics*, September, 1959.

REFERENCES

[1]Doctoral dissertation, Department of Aeronautics, Johns Hopkins University, 1956.

[2]L. M. Milne-Thomson, "Theoretical Hydrodynamics," second edition, New York, The MacMillan Co., 1950, p. 161. The notation used is that of the reference.

A new electro-chemical device has been developed by the Naval Ordnance Laboratory. Called a solion, the device can perform many of the functions of the transistor. The electrical charge is transported by ions in solution rather than by electrons, as in the transistor and vacuum tube. It is said to be extremely sensitive to low energy stimuli, simple to operate, easy to manufacture and to possess inherent stability and long life. Several types have been devised which can be combined for use as very low frequency amplifiers, long period oscillators, and other special devices.

—from NAVAL RESEARCH REVIEWS
May, 1959

A process of controlling the growth of dendritic germanium crystals has been developed by Westinghouse scientists. In this process, the germanium is produced in thin, uniform, flat ribbons, the surfaces of which have a near perfect molecular arrangement which produces a mirror finish. Thus transistors made from the ribbon require no costly and laborious grinding and polishing to produce the desired dimensions, which wastes as much as 80% of ingot germanium in conventional transitor production. This process was developed as a part of a broad effort in the field of molecular engineering which is aimed at improved electronic reliability and a drastic reduction in electronic equipment size and power requirements.

—from WESTINGHOUSE ENGINEER
July, 1959

The Mississippi Shipping Company has ordered three ships of the Friede and Goldman, Inc. "all-hatch" design. Combining an engine aft arrangement with a triple-hatch arrangement in each hold and fast-acting cranes, the design accentuates rapid and efficient cargo handling. Toward this end, the crew and passenger spaces are placed well forward, which makes the entire full middle body section available for cargo storage. Two of the holds will be serviced by a 60 ton boom. Essential features are:

Length, over-all	506 ft.
Beam	70 ft.
Draft	28 ft.
Displacement	16800 tons
Deadweight tonnage	10930
SHP, max. cont.	10600
Speed, 80% SHP	18 kts.

—from MARINE ENGINEERING/LOG
May, 1959

"THE ENGINEER"

ORGANIZING SCIENTIFIC RESEARCH

ACKNOWLEDGEMENT

This is an extract, as published in the 17 April 1959 edition of "The Engineer," of the presidential address at the annual meeting of the Institute of Metals in London in April 1959. The author is G. L. Bailey, Director, British Non-Ferrous Metals Research Association.

It is universal throughout the world that the main effort in pure research is in the universities. Government and industrial laboratories frequently set some effort aside for purely scientific studies with no immediate application in view, but the sum total of their efforts in this direction is probably less than that in the universities. Applied research is the first objective of the industrial research laboratory which is mainly set up to improve the products and the processes of a company and create new ones. Government laboratories, especially those engaged on defense work, necessarily devote most of their effort to applied research. There are, however, other facilities for applied research which vary in different countries; some in cooperative research laboratories, and some in institutes for sponsored research. Nowhere can a hard and fast line be drawn as to what is and what is not suitable research for a particular kind of laboratory. Some highly important results have accrued from the substantial effort devoted by some large industrial laboratories to the purest of pure research. Universities, on the other hand, have made valuable contributions to technology, but I am not in general in favor of the undertaking of applied research in universities. University post-graduate work is mainly a training—a training in both manipulation and in a habit of thought—and the student should not be closely tied to the restricted course essential in solving an industrial problem. More important than this is the necessity to maintain sufficient effort on fundamental work, and complete freedom in university research is a major contribution to this end. The higher educational institutions should give the greatest attention to quality and to making the best use of the exceptional individual.

The institute for sponsored research is generally confined to applied research, since its object is to give service to a particular client, but in some cases work of a basic kind is carried out, financed by profits or, in the case of the Mellon Institute, by endowment. My main object is to try and discover how the research effort of different countries is utilized for these various purposes, what the total effort is, who provides the money and where and how it is spent. Unfortunately, statistics are too meager to permit me to do this properly. Figures for the United Kingdom and for the United States of America are fairly good, but only when related to 1955-56; in other countries the gaps get wider and wider.

A country's research effort can be measured in various ways and in what follows I have tried two methods of assessment: (1) the proportion of a country's scientific manpower devoted to research, and (2) the ratio of a country's research expenditure to the value of either its gross national product or the net output of industry, which I take to be roughly the sales less raw materials cost. Where G.N.P. is used it must be remembered that this figure includes min-

erals and agricultural products as well as "invisible exports" like shipping and insurance. In highly industrialized countries like the United Kingdom or Belgium, where 50 per cent of the active population are engaged in industry, the value of the output of industry is a larger part of the G.N.P. than in more agricultural countries like France, the U.S.A. or the U.S.S.R., in which the proportion of the active population in industry is nearer 35 per cent. The figures given below are approximate and I have made a lot of simplifying assumptions, but I believe the broad picture to be correct.

In what follows, the word "research" is used to cover what is rather loosely known as "research and development" and by "scientists" I mean persons with university degrees or their equivalents in pure or applied science, including engineers. I recognize there are differences in standards in different countries but have had to ignore this. I have not mentioned all the countries for which information exists, but have tried to select as examples countries where the organizations for carrying out research vary considerably.

THE UNITED KINGDOM

Research in the United Kingdom is organized relatively simply, primarily through the Government on the one hand and private and nationalized industries on the other. United Kingdom research expenditure in 1955/56 totalled £300 million, or 1.5 per cent of the gross national product. The Government operates through the Defense Departments which maintain their own laboratories and finance substantial amounts of work elsewhere; the University Grants Committee which provides the majority of finance for university research; and the Lord President of the Council who administers the Agricultural Research Council, the Medical Research Council (with neither of which am I further concerned) and the Department of Scientific and Industrial Research. Of the £300 million mentioned above, £225 million came from the Government; £90,000,000 was spent in its own laboratories, £15,000,000 in the universities, and £120 million in the research laboratories of nationalized or private industry. The D.S.I.R. spends some £5,000,000 in its own research stations which employ about 1300 qualified scientists. These stations serve those sections of industry which are of great national importance, but which are not easily organized on a co-operative basis, as for example, building, mechanical engineering, road research, or provide fundamental data, e.g. the National Physical and Chemical Laboratories. The D.S.I.R. also sponsors and supports financially (to the tune of £1,600,000 in 1957) the co-operative research associations which until recently have been a unique feature of British research organization. There are over forty of these associations, those concerned with non-ferrous metals and with welding being the only ones dealing directly with the industries represented in this Institute. The help from the D.S.I.R. in financing post-graduate research students and in providing special grants for modern and in many cases expensive equipment is of great importance.

Industry spent £70,000,000 of its own money in its research laboratories and some £5,000,000 in the research association. This total of £75,000,000 is half of 1 per cent of the value of G.N.P. and 0.8 per cent of the value of industrial output, and was 40 per cent of the total amount spent in its own laboratories, the remainder coming from Government contracts, mainly defense.

The distribution of expenditure on research in different sections of industry varies widely. Aircraft is by far the largest, spending in 1956 an amount equal to 35 per cent of its net output on research and development. The average for all other industries is 2 per cent of net output of firms employing more than 100 people, with variations of from 0.1 per cent for the clothing industry to 6.8 per cent for electrical engineering. These, of course, include Government expenditure in industrial laboratories which, on the average, would probably be about half the total expenditure of the manufacturing industries if we presume aircraft is in a special position and is more heavily financed by the Government.

The total number of qualified scientists in the United Kingdom in 1956 was 140,000, of which manufacturing industry employed altogether 55,000. The total number of scientists engaged on research and development was 47,000 if it is assumed that half the time of university teaching staff in science departments is devoted to research. If the 29,000 scientists employed on research and development in British industry are divided in accordance with expenditure between Government-sponsored and industry-financed work we arrive at the conclusion that not more than 10,000 scientists were engaged by British industry in 1956 on research work for its own purposes. If it is assumed, at the other extreme, that all aircraft research and development was paid for by Government there would be some 17,500 scientists engaged in British industry on research for its own purposes —a figure of 15,000 is probably fairly near the truth. The research associations employed 1500 of these and thus constituted an important section of industrial research although their combined incomes equal only 2 per cent of the country's gross research expenditure.

THE U.S.A.

In the United States of America no central body existed for the co-ordination of research, like the D.S.I.R. in this country, until a few months ago, when the President established a new Federal Council for Science and Technology to promote closer co-operation among Federal agencies in planning their research programs. There are over twenty departments and agencies of the Federal Government which include estimates for research in their annual budgets. While departments do a certain amount of research in their own laboratories the general trend is towards decentralization, e.g. the placing of contracts

in universities, research foundations and in industry. The majority of the Government research expenditure is naturally related to defense, and, in 1957, 48 per cent of Government work was carried out in industrial laboratories and 17 per cent in non-profit institutions, mainly the universities.

The total research expenditure in the U.S.A. in 1956 (9,000 million dollars) was equivalent to 2.3 per cent of the value of the G.N.P.; 37 per cent of this (3.3 billion dollars or 0.85 per cent of the G.N.P.) was spent by industry for research on its own problems. I have no clear idea how much university research is government or industry sponsored, but it is interesting to note that the independent research institutes, such as Mellon, Battelle and Armour, of which so much is heard, accounted in 1952 for only 2 per cent of the total research expenditure of the U.S.A. About half this was provided by Government and the bulk of the remainder by industry for specific projects, the results of which are confidential to the sponsor. These institutes offer to provide research facilities to the small firm whose resources do not permit the setting up of its own research organization, but their services are in fact more used by the larger companies.

The U.S.A. has in recent years seen some growth of co-operation in the support of research. In 1953, 20,000,000 dollars was spent by co-operative organizations in this way, the main source of funds being trade associations. The Department of Commerce is said to be trying to promote co-operative research through trade associations, and progress in this direction will be watched with interest.

Out of 750,000 scientists in America the number employed in industry in 1954 was 550,000; of these 157,000 were engaged in research. About 100,000 of them were employed by U.S. industry on its own problems, or about three times as many as were so engaged in this country in proportion to the number of the population (160 million in U.S.A.). An interesting sidelight is that of the total 157,000 scientists engaged in research in the U.S.A. two-thirds are engineers, compared with one-half in the United Kingdom total.

FRANCE

Apart from state laboratories the French Government exercises a close control over much research through the Minister for Industry, who is concerned with research in those basic industries such as coal, electricity and gas which are nationalized in France, and the Minister for Education, who not only concerns himself with research in educational institutions but also controls the National Center of Scientific Research (C.N.R.S.). This organization covers natural, medical and "humanistic" sciences and employs some 2500 scientists in fifteen large laboratories and a number of smaller ones in which both fundamental and applied research is carried out with considerable freedom of action to the individual director.

A most interesting development is the Corporate Research Centers set up by branches of industry to serve the trade concerned as a whole or individual undertakings. The state has supervisory functions but, like our D.S.I.R. with Research Associations, rarely interferes with the administrative boards of industrialists. Unlike the research associations, however, they are entirely financed by industry. The methods of financing these centers vary widely but are mainly based on statutory levies which are said to be paid by over 90 per cent of industry. Thus, the French Petroleum Institute (I.F.P.) is financed by a sales tax on petrol, the Foundry Center (C.T.I.F.) by a levy on turnover added to the invoice for castings, and the Ironworks Research Institute (I.R.S.I.D.) by a sales tax on ordinary steel. The Foundry Center, of which I know most, has an income from a levy of approximately £500,000 per annum which is equivalent to about £5 per annum for every worker employed in the industry. This Center probably devotes less than half its resources to research, the main work of its central and nine regional laboratories being in the provision of routine analytical and testing facilities for the entire French foundry industry. It has a technical staff capable of assisting foundries with problems encountered in day-to-day production and provides library and information services. The professional research organizations such as the Centers Techniques, over forty in number, have staffs totalling over 3000.

France's total research expenditure amounts to 0.6 per cent of the G.N.P. if we exclude the universities for which figures are not available. Of this amount industry is said to contribute only about 12 per cent, but I suspect the expenditure on the Centers Techniques should be added to this. I have no figures for the proportion of French scientists engaged in research. There seem to be about 150,000 scientists engaged in French industry—much the same proportion as in the United Kingdom—but further breakdown is difficult.

GERMANY

The Federal German Government plays its part through its own laboratories such as the Physical Technical Federal Institute and through grants to a large number of institutions. The Land governments make some financial contribution to the Max Planck Society for the Promotion of Science. In pre-war days the Institutes of the K.W.I. were well known and after the war thirty-five of these research institutes were re-organized in Western Germany and supported by the eleven Länder which jointly finance the Max Planck Society. Much of the work done in these Max Planck Institutes is financed by industry. For instance, the Verein Deutscher Eisenhüttenleute (the German Iron and Steel Institute) has a number of technical committees which collaborate very closely with the Max Planck Institute for Eisenforschung where the industry, either through the Institute or the individual companies, finances a lot of the work. The directors of these research institutes have complete academic freedom and the visit which we made to Stuttgart two years ago and the Autumn

Lecture which we then heard from Dr. Köster will have given members some idea of the kind of work handled in these institutes.

Two other organizations play a part on a national scale, the Forschungsgemeinschaft (an organization of scientific* and educational institutions) and the Stifterverband (a League of Benefactors for German Science). The first of these receives funds from Government and from subscribers, which are utilized to support individuals working on projects which are beyond their own financial capacity. The second raises money from trade associations and private firms and uses this to finance projects of fundamental or applied nature.

There is a great tendency to encourage donors to contribute to the Stifterverband whose views are listened to with increasing respect by Government and industry in Germany. The number of firms and organizations contributing is between 3000 and 4000, about half of whom have now accepted the new slogan "One per cent of profits to the Stifterverband."

The research work of the industrial laboratories in Germany is now supported by an interesting recent development in co-operative research associations similar in principle to those which have hitherto only existed in the United Kingdom. There are now nearly forty of these associations, but the scope of individual ones is generally rather more restricted. For instance, in the metallurgical field there are six such associations dealing respectively with sheet metal, iron founding, drop forging, casting, hardness and heat treatment, wire drawing and cold rolling. These associations accounted in 1957 for 5 per cent of the industry's total expenditure on research and their future development will be watched with interest.

German industry's research expenditure in these various ways amounted in 1956 to over DM.800 million, about 0.45 per cent of the G.N.P. If we make some estimate of the expenditure of the Länder, the Federal, Land and Municipal Government spend another DM.650 million bringing the whole research expenditure to over 0.8 per cent of the G.N.P.

HOLLAND

While a number of the large industries maintain private research laboratories, Holland is of special interest for the two Government created organizations which look after research—the Organization for Pure Science (Z.W.O.) grants fellowships and subsidizes university research while the Central National Organization for Applied Scientifiic Research (T.N.O.) is responsible for ensuring that applied research serves the public need. T.N.O., which is governed half by representatives of the scientific world and half by representatives of industry, runs about forty research institutes, including one devoted to metals and one to corrosion, and supports suitable research projects elsewhere. These institutes are financed partly by direct Government grants, which are usually earmarked for basic research, and mainly by industrial contributions. These can be used by the institutes for co-operative programs or for a collection of individually sponsored projects, or both.

Holland has a particularly difficult situation in that 162,000 of its 172,000 firms employ less than ten people and only ninety-four firms employ more than 1000. Co-operation is growing in research and in some instances separate co-operative industrial laboratories have been stimulated by the work of the T.N.O. More than half the total research expenditure of the country in 1956 was incurred by industry.

SCANDINAVIA

As elsewhere, state assistance to research in Scandinavia has increased enormously since the war, although a much larger proportion of the working population is employed in agriculture in those countries than in Great Britain or North America and less research effort is directed towards manufacturing industry. In Norway, the Government finances research by normal grants from the state and by the novel step of the devotion to this purpose of a proportion of the profits of national football pools based, I believe, on United Kingdom league games! The Royal Norwegian Council for Scientific and Industrial Research operates a number of Research Institutes such as atomic energy, seaweed, building, and a Central Institute for Industrial Research, modelled to some extent on the American sponsored institutes, while other similar councils deal with agriculture and humanistic and medical sciences. In addition there are one or two private research organizations with certain limited funds available for use as grants to research workers and some co-operative research establishments which have made considerable progress since 1948. None of these operate in the metallurgical field.

In Sweden the learned societies headed by the Royal Swedish Academy of Science, supported partly by the state and partly from private funds, to some extent initiate and co-ordinate research and publish results. The state has set up four research councils to follow the research activities in Sweden within their fields and promote research by grants for definite research projects; the three biggest of these deal with natural science, technical research and medicine.

Research in the universities and institutes of technology, is financed mainly by research councils and state agencies and partly by industry, but there are also a number of research institutes operating in particular fields which are mainly financed by industry. In our own field the Metallografiska Institutet is the interesting one operating in the general (largely ferrous) metallurgical field from Stockholm. The part played by Jernkontoret in Swedish metallurgical research is particularly interesting. This

*It must be remembered that the German word "Wissenschaft" which is generally translated "science" includes humanities.

Swedish Iron Masters' Association, founded over 200 years ago, organizes research on a considerable scale. The industry provides the funds, Jernkontoret organizes a number of research committees and the work is placed in industrial laboratories, works departments and particularly in the Metallografiska Institutet and the various departments of the Royal Institute of Technology in Stockholm.

Denmark relies heavily on universities and on the institutions through which the Academy of the Technical Sciences works. Some twelve such organizations work in fields of technology—the Danish Laboratory for Welding being an example—and most of the working expenses are met by industry. Denmark is also fortunate not only in the well-known products of Carlsberg but in the funds provided by this beneficent organization for endowing the Carlsberg Foundation for extending knowledge in brewing, biology and in natural sciences.

RUSSIA

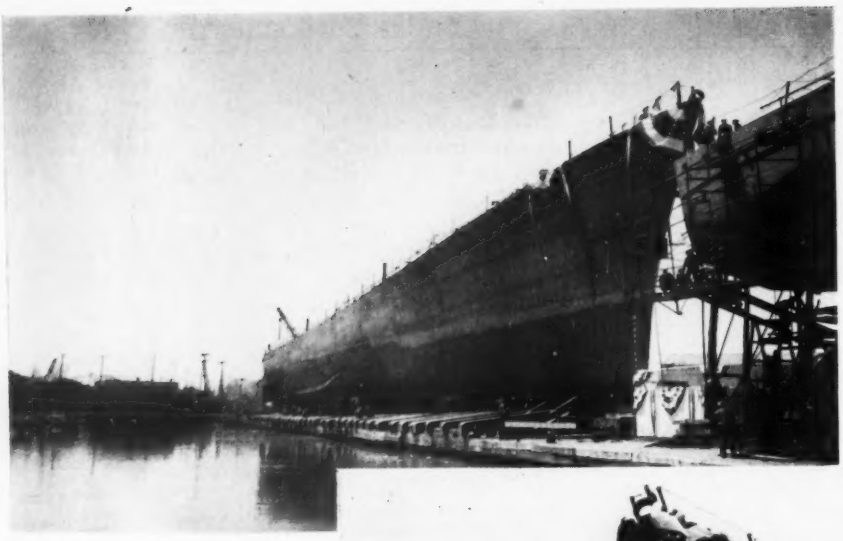
One would very much like to compare the picture in Western Europe and in America with that in Russia, but it is difficult to find sufficient facts to make such a statistical comparison. One thing we do know from such information as has been gleaned from all the available sources is that the percentage of research expenditure to G.N.P. is probably at least as high in the U.S.S.R. as it is in the U.S.A. Most of the money comes as an appropriation in the State Budget, with another 20 per cent or so directly from industry. On scientific manpower there is some information which suggests that in 1954 there were 700,000 qualified scientists in Russia, apart from agriculture, of whom about 100,000 were employed in research and development.

The population of Russia (200 million) is larger than that of the U.S.A. and on this basis one might assume that a few years ago the Russian research and development effort was about half that of the U.S.A. Russia is, however, training scientists more rapidly than anyone else. The organization aims to prepare a scientist highly qualified in a specialist field. The normal course of training is about five and a half years, which includes something like three years of specialization. In the metallurgical field, specialization of a ferrous metallurgist might be restricted to the blast-furnace or to open hearth metallurgy. This scheme, it has been stated by Holloman, works well now, but in ten years' time these "narrow people are likely to be unsuited for the further development of the metallurgical industry." The rate at which people trained in this way are turned out is, however, quite striking. In 1954, 70,000 scientists, excluding agriculture and medicine, successfully completed a five and a half year course of training. This compares with 36,000 in the U.S.A. and 11,000 in the United Kingdom. These figures must not be taken as strictly comparable because of differences in standards and qualifications. Research in Russia is carried out mainly in large centralized research laboratories such as those connected with the Academy of Sciences and more particularly the industrial laboratories set up to study the problems of the country and industry as a whole rather than the problems of a particular company or an industrial segment.

Scientists in Russia are, however, treated as persons of importance. Not only are they rewarded more attractively than most other workers, but again, according to Holloman, they can translate research into practice more quickly because the country has greater confidence in scientists and in their contribution to society.

A one-ton boat designed to act as a test vehicle for supercavitating hydrofoils and supercavitating propellers is under development by the Navy. The craft is 24 feet in length and is expected to attain a speed of 60 knots. Built at Dynamic Developments, Inc., the boat will be powered by a General Electric T-58 aircraft type gas turbine.

—from BUREAU OF SHIPS JOURNAL
May, 1959



U. S. S. Wilson (DDG-7) is shown before, during, and after her side-launching in the sequence of photographs. The launching took place on April 22, 1959 at the Defoe Shipbuilding Company, Bay City, Michigan. *Wilson* is the first destroyer type built on the Great Lakes and is expected to be the first combatant ship to be delivered to the fleet via the St. Lawrence Waterway.

HARRY E. YARNELL

The Society's twenty-sixth President, Admiral Harry E. Yarnell, U. S. Navy, Retired, died on the seventh of July in his 84th year.

Admiral Yarnell is best remembered, by the people with whom he served for nearly 45 years of active duty, for his forthright statesmanship while he was Commander-in-Chief of the Asiatic Fleet. He served in this command during those critical years from 1936 to 1939 when the Pacific phase of World War II was in the making. His firmness in dealing with the Japanese in every situation, which included the sinking of the "*Panay*" on the Yangtse river in 1937 and the warning by the Japanese to evacuate Swatow in 1939, probably delayed the war which he believed to be inevitable to a period when the United States was basically much more capable of waging it.

Admiral Yarnell's active duty began when he graduated from the Naval Academy in 1897. He saw combat duty in the Spanish American War, the Boxer Rebellion and the occupation of Vera Cruz. Although he retired in 1939 he was recalled for active duty during World War II and served in special capacities in Washington from 1941 to 1944.

He graduated fourth in his class at the Naval Academy at the time that engineering cadets had been eliminated and the Engineering Corps was in the process of abolishment and so necessarily entered the service as an unrestricted line officer. In September 1928 he was appointed Chief of the Bureau of Engineering and Engineer-in-Chief of the Navy and served with distinction until May 1931.

Admiral Yarnell joined the Society in 1909 and was elected its President in 1929 and reelected in 1930.

NOTICE

As stated in the Secretary's Notes relief has been granted for dues of members of the American Society of Naval Engineers who are subject to the British income tax. This was done at our request and we have been told that those seeking this relief should follow these instructions:

"Commencing with the year to 5 April, 1959, a member who is assessable to income tax under Schedule E in respect of the emoluments of an office or employment is entitled to a deduction from those emoluments of the whole of the annual subscription which is due and payable by him to the society in the income tax year provided that—

(a) the subscription is defrayed out of the emoluments of the office or employment, and,

(b) the activities of the society so far as they are directed to all or any of the following objects—

  (i) the advancement or spreading of knowledge (whether generally or among persons belonging to the same or similar professions or occupying the same or similar positions):

  (ii) the maintenance or improvement of standards of conduct and competence among the members of any profession;

  (iii) the indemnification or protection of members of any profession against claims in respect of liabilities incurred by them in the exercise of their profession;

are relevant to the office or employment, that is to say, the performance of the duties of the office or employment is directly affected by the knowledge concerned or involves the exercise of the profession concerned.

A member of the society who is entitled to the relief should apply to his tax office as soon as possible for form P358 on which to make a claim for adjustment of his pay as you earn coding."

BOOK REVIEWS & NOTICES

LOGISTICS IN THE NATIONAL DEFENSE
By
Rear Admiral Henry E. Eccles, U.S. Navy, Retired
Foreword by
Dr. Henry M. Wriston,
President of the American Assembly,
Columbia University
Published by
The Stackpole Company
(formerly The Military Service Publishing Co.)
Harrisburg, Pennsylvania
329 pages $5.00

This book, if read and assimilated by enough of the right people in the United States could have a very profound effect on the future of the country. It might well be required reading for every civilian or military executive who may ever be faced with decisions which could affect the defense posture of the country during periods of preparation or of readiness for or of execution of war.

It is a thinking man's book without a filter. Admiral Eccles presents no formulae of specific action nor any rosy-hued picture of satisfactoriness. He makes it quite clear that if the right people give full consideration to the right things the dangers of economic disaster before or during a war on account of the cost of the military establishment and of disaster in war can be reduced.

His many historical references which add much to the interest and ease of reading of the book make it quite clear how much the cost of faulty decisions in the past has been and how easy it is to visualize exactly the same kind of faulty decisions being made today and tomorrow.

Admiral Eccles makes strikingly clear how many intangibles there are in the wide field of logistics which is variously defined but probably as well, broadly, in the following quotation from Ballantine

> "As the link between the war front and the home front the logistic process is at once the military element in the nation's economy and the economic element in its military operations"

as it can be done.

He leaves no doubt that the intangibles cannot be glossed over nor taken for granted. They cannot be taken care of by formalism. Only when the commander or executive considers them all in the circumstances of the moment and makes his decisions with full consideration of the effects and counter-effects and cross-effects of the intangibles as well as the tangibles, can the optimum effect be obtained.

This reviewer knows of no other individual who possesses the combination of experience, erudition, intuitive research instinct applied to reading and ability to write which make Admiral Eccles the natural author of this book. As a professional military man he has successfully bridged the gap which sometimes separates his class from the rest of the world.

HELICOPTERS AND AUTOGYROS OF THE WORLD

By PAUL LAMBERMONT *with* ANTHONY PIRIE

Published in 1959 by
Philosophical Library, Inc.
15 East 40th Street, New York 16, N. Y.
Price $10.00 255 pages of texts and illustrations

Reviewed by W. E. BRODOWSKI,
Ship Design Division, Bureau of Ships

The helicopter is without a doubt the most utilitarian aircraft in the world today. With its rise in importance and popularity has come the need for a reference or catalog of the many types now in existence. This is precisely what the author has done in this comprehensive study of helicopters and autogyros.

For the practicing aeronautical engineer this volume is an ideal reference. For the person somewhat familiar with aircraft and interested in the design and the history of the design of helicopters and autogyros, it is an excellent starting point. It is understandable that in a work of this magnitude the amount of detail must be limited to the vital statistics. These are given in tabular form. It is regrettable, however, that the author did not include a bibliography; particularly since, in his capacity as editor of the monthly bulletin of the International Aeronautical Federation, he has had every opportunity to obtain the most accurate and complete information on the world's helicopters. A check of a few well-known American designs bears out the accuracy of the technical details included.

To assure ready reference, the products of each of twenty-two nations dealt with are treated in separate sections. Each section is then subdivided according to the manufacturer and further to each machine. In all, some 170 manufacturers and over 425 machines are included.

The catalog is prefaced by a 5 page historical survey which briefly summarizes only the most significant attempts at rotary wing flight.

Also included in the volume are: a complete list of recognized records and record holders; official definitions of the types of rotary wing craft; 133 illustrations; and an index of personalities.

The principal value of this book lies in the fact that its comprehensive list of helicopters and the most pertinent details of each are assembled within a single cover.

HIGH ALTITUDE AND SATELLITE ROCKETS

A Symposium sponsored by
The Royal Aeronautical Society
The British Interplanetary Society
and The College of Aeronautics
held at Cranfield, England, 18-20 July 1957
Published in 1959 by
The Philosophical Library, Inc.
15 East 40th Street, New York 16, New York
Price $15.00 136 pages

The Proceedings of the first Symposium on high altitude and satellite rockets to be held in Great Britain, before the Russian and American satellites were launched, was attended by some 200 delegates from six countries.

The 12 papers in this Proceedings, by British and American authors, are of interest to all those wishing to learn something of the problems of high altitude flight. They deal with some of the design problems and the propulsion problems of high altitude rockets, recovery after re-entry, high temperature materials, instrumentation, telemetry and guidance and some of the human problems of flight beyond the atmosphere; one paper describes the British Skylark upper atmosphere sounding rocket and another the American Vanguard satellite launching vehicle.

THE UPPER ATMOSPHERE

By H. S. W. MASSEY *and* R. L. F. BOYD

Published in 1959 by

Philosophical Library, Inc.

15 East 40th Street, New York 16, N. Y.

Price $17.50 333 pages

This is an authoritative account of the phenomena of the upper atmosphere studied during the International Geophysical Year. Present-day knowledge of the subject is outlined and the techniques used in investigation are fully described. These include the use of Sound and Radiowaves, Spectroscopic devices, Searchlights, Balloons, Rockets and Artificial Satellites. Methods of finding the positions and speeds of rockets and satellites, and of interpreting their coded signals, are explained.

Among the phenomena to receive detailed attention are Radio Fadeout, Radio Absorption, Night Airglow, Aurorae, Meteors, Cosmic Rays, and currents responsible for Magnetic Variations. The effects produced in the atmosphere by the sun, which include the ionized regions so important for long-distance radio transmissions, are described in relation to solar phenomena.

Subjects such as these cannot be explained without the use of mathematics, though there is nothing in this book requiring advanced knowledge and some chapters succeed in avoiding mathematical exposition altogether. This is a book for students, for scientists in other fields who require a reliable outline of the subject, and for those technically interested in space travel.

ELECTRICAL SAFETY

By H. W. SWANN

Published in 1959 by

Philosophical Library, Inc.

15 East 40th Street, New York 16, N. Y.

Price $15.00 101 Illustrations, 292 Pages

Reviewed by JAMES J. MOYER

Electrical Engineer, Ship Design Division

Bureau of Ships

At last a book has been written which describes in a language not too technical the chief causes of electrical accidents and the means to avoid them. Although the author declares that the book is intended for engineers, it is written in such a clear manner as to be an excellent reference for the layman also.

Since the main theme is the preservation of human life, any emphasis on its practical value would be superfluous. And, although it describes British practice, the principles involved have world-wide application.

The author, H. M. Senior Electrical Inspector of Factories and Electrical Adviser to the British Home Office from 1922 to 1953, attracts the reader's interest in the first chapter by presenting a brief history on electrical accidents with some interesting statistics on fatalities both industrial and domestic. The chief cause of these accidents, as any others, is attributed to carelessness and the need for safety education is stressed.

Chapter two describes the physical aspects of electricity. The passage of one-tenth of an ampere for a fraction of a second through the cardiac region may be fatal. The writer points out that although artificial respiration may be satisfactory in restoring the breathing of a drowning casualty, some means of applying either a mechanical or electrical counter shock should be developed for restoring consciousness to a victim of electrical shock.

In the succeeding chapters the author discusses the Electricity Regulations and how the proper interpretation and application of those regulations promote electrical safety. One of the chief causes of fire on ships during the latter stage of construction is the absence of a good solid ground (referred to as earth in England) to the piece being worked in an arc welding process. Also, electrical shocks have been experienced on shipboard due to a difference of potential between the ship and a dockside crane or wire rope, indicating that a floating ship is not as well grounded as some may like to believe.

The chapter dealing with the regulation on auto-

matic protection by means of circuit breakers, fuses and grounding of portable tools is of special interest to the home-owner and do-it-yourself man. The importance of low-impedance grounding is stressed.

Chapter eight is one of the most interesting and important in the book; it deals with the regulation regarding exposure of electrical equipment to inflammable surroundings or explosive atmosphere. The use of flameproof equipment is indicated as essential in this type of environment. The gravity of this regulation lies in the devastating effect an explosion usually has in chemical and gas installations. The author includes many vivid descriptions of actual accidents caused by violation of the electrical regulations. One such illustration involved the loss of eleven large bombers during the war. A small open-type electric motor has been improvised for pumping gasoline into the carburetor of a standing aircraft to test for adequate flow. Another danger area dealt with extensively is the medical operating room where the possibility of anaesthetic explosions exists.

The final chapter deals with a hazard which is ever present and yet not given much serious thought, namely, static electricity. Means of minimizing this condition in danger areas, again where explosive vapors may be present, are indicated. The author points out that the risk of static build-up at nozzles has led to semi-conductive hoses and the grounding of metallic nozzles used to fill oil and gas tanks.

An appendix dealing with the safety aspects of domestic electrical installations brings this comprehensive treatise to a close. The fact that fuse protection is no guaranteee for complete electrical safety in the home is stressed. The author summarizes by suggesting that if more attention is given to the adequacy of the consumers protective arrangement, the need for large-scale inspection of installations and appliances already in use may be minimized. There is every indication that, in spite of the pyramiding use of electrical equipment, steady progress in electrical safety will be made. This sentiment is prompted by the increased interest in so vital a subject shown both by organizations and individual engineers.

Although this book is intended primarily as an aid to industrial engineers in promoting electrical safety, the chapters dealing with domestic installations and appliances make it an attractive addition to the home library. By an appreciation of the more common electrical hazards that are described, the family man can take steps to reduce the likelihood of loss of life and property in his home.

BOOKS RECEIVED

"Ship and Boat Builder Annual Review 1959", compiled by the editorial staff of "Ship and Boat Builder"; published in 1959 by John Trundell Ltd., St. Richard's House, Eversholt Street, N.W. 1, London, England; 389 pages, 50 shillings net.

"The Modern Slide Rule", by Stefan Rudolf, published in 1959 by The William-Frederick Press, 391 East 149th Street, New York 55, N. Y.; 58 pages, $5.00.

"Electric Motors and Generators", by E. T. G. Emery, F. Harrabin, B. C. Lee, J. H. R. Nixon and E. T. A. Rapson; published in 1959 by Philosophical Library, Inc., 15 East 40th Street, New York 16, N. Y.; 384 pages, $12.00.

"Automation and Society", edited by Howard Boone Jacobson and Joseph S. Roucek; published in 1959 by Philosophical Library, Inc., 15 East 40th Street, New York 16, N. Y.; 553 pages, $10.00.

"Concise Dictionary of Science", by Frank Gaynor, published in 1959 by Philosophical Library, Inc., 15 East 40th Street, New York 16, N. Y.; 546 pages, $10.00.

CHANGES IN MEMBERSHIP

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The Society announces with pleasure that the following have joined its ranks since the publication of the May, 1959, issue of the JOURNAL:

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TRANSFERRED—JUNIOR TO NAVAL

Green, David Lorance, LTJG, USCG

REINSTATED

Andersen, Roland M., LTJG, USNR .....Naval
King, Donald C., CAPT., USNR.....Naval
Marin, Antonio, RADM, Argentine Navy.....Associate

RESIGNATIONS

Adams, Richard D. .....Naval
Betz, Robert F. .....Associate
Helsel, Walter David Civil
Husband, William P., Jr. .....Associate
Keachie, James Harold Civil
Miles, Arthur Clark, Vice ADM, USN (Ret) ....Naval
Rentschler, Walter A. .....Associate

DEATHS

Cullen, Julius Adolph.....Civil
Gosnell, H. A., LCDR, USNR.....Naval
Schlueter, August .....Associate
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The rules for manuscripts are as simple as we can make them.

1. They must be legible (typewritten, double-spaced preferred) since no proof is submitted to authors for correction prior to printing.

2. Single copy only is required.

3. Mathematical formulae used must be set up, preferably by hand printing, so that there can be no question as to symbols, subscripts and exponents.

4. Any drawing submitted must be black on white. A cloth or paper tracing is acceptable but not required.

5. Photographs may be negatives, but glossy prints are acceptable.

6. *Include on a separate page a short biographical sketch(es) of the author(s).* 50 to 100 words for each author is desired.

Manuscripts should be addressed to:

Secretary-Treasurer
American Society of Naval Engineers, Inc.
1012 14th St., N.W.
Washington 5, D.C.

Each author who is subject to the Security Regulations of the Department of Defense, is personally responsible for the clearance of an original article before submitting it to the Society for consideration. In forwarding manuscripts, a statement in this regard should be included.

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Photographs of current or historical interest to readers of the JOURNAL are desired. Any which are accepted by the Society will be purchased by the Society at a standard price of $5.00 each. Such purchase *will not* include any copyright by the Society, but the contributor must hold the Society free from any charge of violation of any previous copyright.

NOTICE OF DEATHS

The Society has no satisfactory machinery for obtaining notice of deaths of members. It is particularly desired that we receive such notice upon the death of any past officer, past member of the Council or member of more than twenty years' standing with photographs and short obituaries. It will be appreciated greatly if any member who learns of the death of a member will advise the Secretary-Treasurer.

SOCIETY LAPEL BUTTONS

We have a new supply of lapel buttons, in the form of the Society's official seal. These may be purchased by any member for fifty cents ($0.50) each.

By decision of the Council the official coloring of the Society seal is as it appears on the cover of this Journal. This is a reversal of the colors on the old lapel buttons. The size, one-half inch in diameter, remains the same.

Any member who wishes to exchange an old button for a new one may do so *free of charge*. Just send in the old button with your name and address.

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Undergraduates at schools to be named by and under regulations to be issued by the Council shall be admitted as Junior Members at one-half the dues of regular members during their course and for one year following graduation, after which time junior membership will be terminated, the member to have the privilege of transferring to regular membership in the appropriate category.

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*Names in italics deceased

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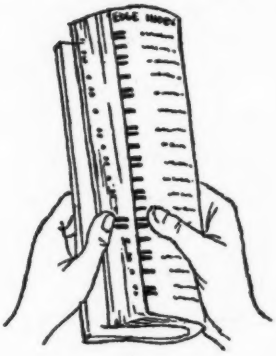

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